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Findings of a study to quantify and then evaluate the contribution of initial soil flooding and decomposition of vegetation to the water quality of the newly filled Richard B. Russell Lake are reported herein. Samples of soils and vegetation were taken from three areas representing the most predominant types of soil vegetation within the boundaries of the lake. Using controlled conditions in the laboratory, it was found that both soils and vegetation can release significant quantities of oxygen-consuming materials and plant nutrients.
(Continued)

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20. ABSTRACT (Continued).

Soil samples had an oxygen demand large enough to cause strong depletion of dissolved oxygen from the overlying water at 5° and $12.5^\circ C$, while samples held at $20^\circ C$ removed all dissolved oxygen within 30 to 40 days. Development of anoxic conditions resulted in the release of large quantities of dissolved organic matter, plant nutrients, iron, manganese, and hydrogen sulfide.

Upon comparison of these observations with other preimpoundment and postimpoundment investigations, several measures of potential use were found to reduce the impact of initial soil flooding and decomposition of vegetation on the initial water quality of Richard B. Russell Lake. These included: burning of herbaceous vegetation in the hypolimnion and removal of tops trimmed from trees from areas to be flooded by project waters; application of the data in this report to reservoir operation through use of a mathematical water quality model; reduction of residence time for hypolimnetic waters in the reservoir through operation of the sluice gates; and use of the planned dissolved oxygen injection system during initial reservoir filling.

PREFACE

This study was conducted by the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., for the U. S. Army Engineer District, Savannah (SAS). The project was authorized by Intra-Army Order for Reimbursable Services No. EN-CP 80-146 dated 10 June 1980, amended 14 December 1981.

This report is an evaluation of the potential water quality effects of initial filling and decomposition of vegetation in Richard B. Russell Reservoir.

The research was conducted under the direct supervision of Dr. Robert M. Engler, Chief, Contaminant Mobility and Regulatory Criteria Group, and under the general supervision of Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division, EL, and Dr. John Harrison, Chief, EL. Dr. Douglas Gunnison, Aquatic Processes and Effects Group (APEG), served as principal investigator. Mr. James M. Brannon, Dr. Rex L. Chen, Mr. Isaac Smith, Jr., and Mr. Thomas Sturgis, APEG, participated in the study.

Commanders of the SAS during the preparation and publication of this report were COL Tilford C. Creel, CE, and COL Charles E. Dominy, CE. Commanders and Directors of the WES during the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

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CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
gallons (U. S. liquid)	3.785412	cubic decimetres
miles (U. S. statute)	1.609347	kilometres

RICHARD B. RUSSELL DAM AND RESERVOIR: POTENTIAL WATER QUALITY EFFECTS OF INITIAL FILLING AND DECOMPOSITION OF VEGETATION

PART I: INTRODUCTION

1. Richard B. Russell Lake will be formed by the impoundment of a section of the Savannah River. The damsite is located on the Georgia-South Carolina border approximately 30 miles* below Hartwell Dam, 37 miles above Clarks Hill Reservoir, and 275 river miles above the mouth of the Savannah River. The project was authorized by the Flood Control Act of 1966 and will be operated for flood control, hydropower, and recreational purposes.

2. The objectives of the study presented herein were to quantify and then evaluate the contribution of initial soil flooding and decomposition of vegetation to the water quality of the newly filled impoundment. The study examined only the consumption of dissolved oxygen (DO), the release of specific nutrients and metals, and the formation of materials having high biochemical and chemical oxygen demands (BOD and COD, respectively). As indicated in the scope of work presented to the U. S. Army Engineer District, Savannah (SAS), by the Environmental Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), this study did not attempt to examine the overall effects of reservoir hydrodynamics on the dilution and transport of the materials released from the inundated soil and decomposing vegetation to the water column. This would require the application of a process-oriented water quality numerical model.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

PART II: METHODS AND MATERIALS

Sampling Sites

3. Three generally representative areas from within the bound-
aries of the Richard B. Russell Lake were selected as sampling sites.
Although a larger number of sites would have been desirable for a
26,000-acre impoundment, financial considerations restricted the number
of areas that could be studied. The areas selected represent the most
predominant types of soil and vegetation in the reservoir basin. The
general locations of these sites are depicted in Figure 1. Major vege-
tative and edaphic considerations for each of the sites are presented
below. Vegetation for the entire project area, described in detail in
U. S. Army Engineer District, Savannah (1974), is characterized as a
mixed hardwood (oak-hickory) and pine (shortleaf-loblolly) forest cover.

4. Site 1 is approximately 0.6 km northeast of the Tates Grove
Baptist Church and 1.2 km northwest of the damsite in Elbert County,
Georgia. Site 1 was selected as representative of the most extensive
soil type lying within the lake boundaries. The soil in the area is
poorly drained, loamy alluvial soil, subject to periodic flooding. At
Site 1, pines represent approximately one third of the mixed hardwood
and pine cover.

5. Site 2 is on the Georgia side of the Savannah River and is
adjacent to McCalla Island, approximately 17 km east-northeast of the
city of Elberton, Georgia. Site 2 was selected as representative of
the second most extensive soil type within the lake area: sandy gravel
loams underlain by clay. Vegetation, similar to Site 1, is mixed hard-
wood and pine with pine comprising approximately one half of the cover.

6. Site 3 is located in Anderson County, South Carolina, approxi-
mately 300 m northwest of the Abbeville-Anderson county line and 50 m
below an abandoned hydropower structure. Soils in this area represent
the third most abundant soil type and are characterized as fine sandy
loam. Area vegetation contains a preponderance of small trees and
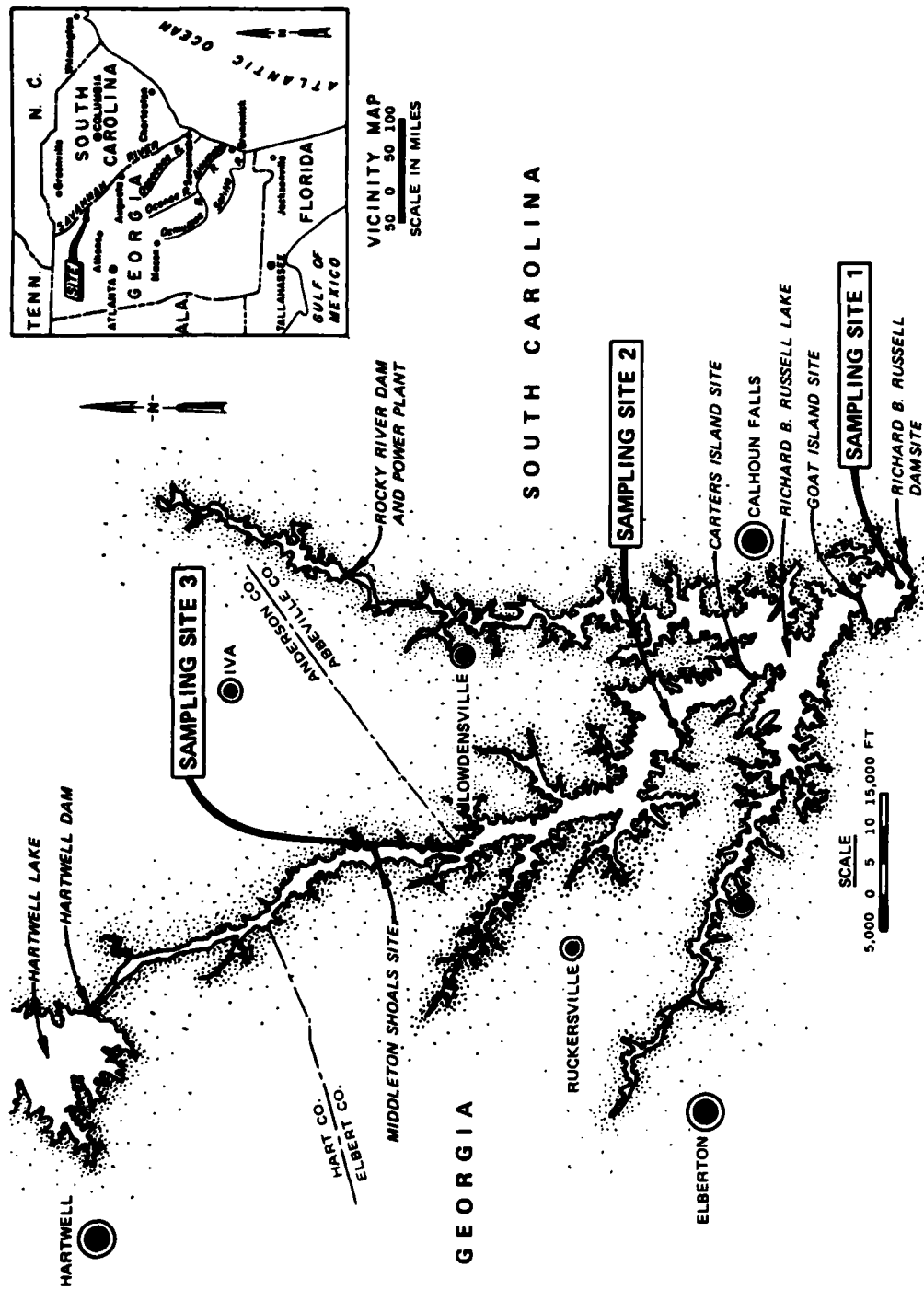shrubs with willow and dogwood being common.

Figure 1. Location of sampling sites used in this study

Sampling Procedures

7. Soil samples were collected by cutting the soil away from the perimeter of an 0.5-m^2 area down to approximately 20 cm beneath the boundary of the A- and B-horizons. Samples were removed and placed onto individual sheets of 5-mil-thick polyvinyl chloride (PVC) plastic prior to placement in shipment containers. The samples were transported to WES by motor freight. Samples were received at WES within 1 week; these were still moist, and plants on soil surfaces were still green.

8. In the case of each site, none of the large trees and shrubs present were included with the soil samples, although any roots running through the various horizons and litter lying on the surface of the A-horizon were included. Samples of twigs and leaves were removed from the trees and shrubs present along with mosses and grasses in the area of all sites (each in approximate proportion to the biomass of the type of cover present as determined by visual inspection), composited, and placed into individual, heavy-duty 30-gal trash bags for transport to WES in the shipment containers with the soil samples.

Laboratory Procedures

Experimental design

9. At WES, the samples were placed into reaction chambers for experimental analysis. The general design of the soil-water reaction columns, the instrumentation (system circuit attached) to these columns, and the flow-through system providing constant inflow of synthetic river water used in this study are explained in Gunnison et al. (1980) and are reviewed in Appendix A. Individual samples of soil, trimmed to squares of approximately 0.45 m on each side, were then placed into the soil-water reaction columns. For each study site, two replicate soil samples were set up for each of three incubation temperatures to be examined (3 sites × 3 temperatures × 2 replicates = 18 columns).

10. Prior to the initiation of an experiment, synthetic Savannah River water containing the compounds listed on the next page was added

Synthetic River Water Composition

Compound	Concentration, mg/ℓ
$NaHCO_3$	12.00
$CuSO_4 \cdot 2H_2O$	7.497
$MgSO_4$	7.497
KCl	1.703
NH_4Cl	0.0573
KH_2PO_4	0.0877
KNO_3	0.9376
$FeCl_3 \cdot 6H_2O$	1.451
$MnCl_2 \cdot 4H_2O$	0.4679

to the inflow water storage tanks at the concentrations indicated. This combination of ingredients was selected as that which most closely simulated the average yearly composition of the Savannah River (data supplied by Dr. David Kendall, formerly of SAS). The water in the storage tanks was actively charged with air for a minimum of 24 hr prior to flooding of the soil samples. Reaction columns were filled with synthetic Savannah River water to the overflow point, and the soil-water contents of each unit were permitted to equilibrate for at least 1 week with constant aeration and mixing, as decided in consultation with SAS. After equilibration, an initial sample was taken to provide baseline data under aerobic conditions. After initial sampling, aeration was discontinued, and the reaction columns were sealed off from the atmosphere. As agreed upon in discussions with SAS, the soil immersion studies were run using the reaction chambers in the continuous flow mode. Flow-through conditions were initiated at a rate approximating a 20-day residence time for the water in the reaction column. As decided in consultation with SAS, incubation temperatures examined were 5°, 12.5°, and 20°C. This set of temperatures bracketed the full range of temperatures expected in the reservoir. The circulation pump achieved a turnover of reaction column water once every 2 min; this was used to ensure complete mixing of inflows with the water column and to enable samples taken to be representative of the entire water column.

11. Reaction columns were run steadily for 100 days and sampled

for the various physical and chemical parameters except DO at 0, 10, 15, 25, 50, 75, and 100 days. The DO content was measured daily from the initiation of the experiment up to the point where it was no longer detectable or for a period of 30 days, whichever occurred first. In the latter case, DO was subsequently measured at 10-day intervals.

Measurement of DO, pH, conductivity, and color

12. Dissolved oxygen, pH, and conductivity were measured on samples collected by permitting water to flow gently from a reaction column sampling port into a standard BOD bottle. Dissolved oxygen was determined with the azide modification of the Winkler method as described in Standard Methods (American Public Health Association (APHA) 1980). Conductivity was measured with a YSI Model 31 Conductivity Bridge using a YSI Model 3403 Conductivity Cell (Yellow Springs Instruments, Yellow Springs, Ohio). The pH was determined with the combination glass electrode, while color was analyzed using the spectrophotometric procedure given in Standard Methods (APHA 1980).

Methods of sample collection, preservation, and analysis

13. If a reaction chamber became anoxic, all procedures were conducted under a nitrogen atmosphere to maintain the anaerobic integrity of the samples; otherwise, the tests were done under air. Samples to be analyzed for soluble nutrients or for dissolved total inorganic and organic carbon (TIC and TOC, respectively) were cleared of particulate matter by passage through a 0.45-μm membrane filter. Samples for particulate plus dissolved organic carbon (DOC) were not filtered. Samples for dissolved metals analysis were passed through 0.10-μm filters, a treatment shown to remove all particulate and colloidal metals (Kennedy, Zellweger, and Jones 1974). Samples for total sulfide were taken and preserved simultaneously using zinc acetate; analysis was conducted immediately using the methylene blue method, as described in Standard Methods (APHA 1980).

14. Samples for total or soluble nutrients were preserved by acidification with HCl and immediate freezing and storage at -40°C.

9

Samples for TOC and TIC analysis were processed immediately on a Beckman Model 915A Total Organic Carbon Analyzer. Metal samples were preserved by acidification with concentrated (11.6 $\underline{N}$) HCl.

15. Metal concentrations were determined using direct flame aspiration with a Spectrometrics Spectraspan II Ecelle Grating Argon Plasma Emission Spectrophotometer. Nutrient concentrations in water samples were determined using a Technicon Autoanalyzer II. Sulfate concentrations were determined turbidimetrically following conversion of sulfate ion to a barium sulfate suspension (APHA 1980).

Soil characterization

16. Prior to any soil analysis, approximately 1000 g of soil from each of the study sites was air dried, passed through a 120-mesh sieve, and mixed thoroughly. These samples were used to determine the following:

$\underline{a}$. Concentrations of metals including iron (Fe), manganese (Mn), potassium (K), and calcium (Ca).

$\underline{b}$. Concentrations of nutrients including ammonium-nitrogen (NH_4-N), orthophosphate phosphorus (OPO_4-P), and sulfate (SO_4^4).

$\underline{c}$. Particle-size distribution using the sedimentation method, as modified by Patrick (1958).

Test procedures are described in the following paragraphs.

17. **Water extract.** A 40-g subsample of each soil was weighed into a 500-ml centrifuge bottle containing 200 ml of distilled water. The mixture was shaken mechanically for 1 hr and centrifuged at 6000 rpm for 10 min. The resulting supernatant fluid was filtered through 0.45-μm membrane filters, and this filtrate was immediately frozen at -60°C until analyzed for Ca, magnesium (Mg), chloride (Cl), K, and SO_4.

18. **Ammonium acetate extract.** A 20-g subsample of each soil was weighed into a 250-mℓ centrifuge bottle containing 100 mℓ of 1 $\underline{N}$ ammonium acetate (pH 4.8). The mixture was mechanically shaken for 1 hr, centrifuged as described above, and then filtered through 0.45-μm membrane filters. Resulting filtrates were acidified to pH 1 with HCl and stored in polyethylene bottles for subsequent analysis.

19. **Hydroxylamine hydrochloride extraction.** A subsample of each

soil (2.0 g dry weight) was weighed into a 250-ml centrifuge bottle containing 100 ml of 0.1 $\underline{M}$ hydroxylamine hydrochloride and 0.01 $\underline{M}$ nitric acid solution (Chao 1972). The mixture was shaken mechanically for 30 min and centrifuged as previously described. Supernatant solutions were filtered through 0.45-µm membrane filters prior to acidification with HNO_3 to pH 1 and stored in polyethylene bottles for subsequent analysis.

20. <u>Acid leachate analysis.</u> A 2.0-g subsample of soil was weighed into a Teflon beaker containing 25 ml of 8 $\underline{N}$ HNO_3. The mixture was digested for 1 hr at approximately 82°C on a hot plate (Carmody, Pearce, and Yasso 1973). The extract was then filtered through Whatman No. 5 filters, brought to a final volume of 50 ml with distilled water, and stored prior to analysis.

21. <u>Potassium chloride extract.</u> A 20-g soil subsample was weighed into a 250-ml centrifuge bottle containing 100 ml of 1 $\underline{M}$ KCl. The mixture was shaken mechanically for 1 hr, centrifuged as previously described, and then filtered through 0.45-µm filters. The filtrate was acidified to pH 1 with concentrated HCl and stored in polyethylene bottles until analysis.

22. <u>Cation exchange analysis.</u> A 2.0-g subsample of each soil was saturated with ammonium by shaking for 1 hr with 1 $\underline{N}$ ammonium acetate. Excess ammonium was removed by repetitive washing with isopropyl alcohol (Jackson 1958). The absorbed ammonium was then removed by extraction with a series of 2 $\underline{N}$ solutions of mixed K and Ca nitrates, 1.2 $\underline{N}$ KNO_3, and 0.8 $\underline{N}$ $Ca(NO_3)_2$, respectively (Tucker 1974).

23. <u>Total Kjeldahl nitrogen (TKN).</u> A 0.5-g subsample of each soil was weighed into a micro-Kjeldahl flask containing 1.1 g of digestion mixture (100 g of K_2SO_4, 10 g of $CuSO_4 \cdot 5\ H_2O$, and 1.0 g of selenium (Se)), 2.0 ml of H_2O, and 3.0 ml of concentrated H_2SO_4. The mixture was boiled for 5 hr after the digest had cleared. The digest was allowed to cool, diluted with distilled water, and filtered quantitatively through Whatman No. 5 filter paper into a 50-ml volumetric flask. This solution was then stored for subsequent NH_4-N analysis.

24. <u>Carbon.</u> Total organic carbon was estimated after assessing

11

total organic matter by weight loss following heating 10 g (oven-dry weight) of soil for 8 hr in a muffle furnace at 400°C (Davies 1974). The resulting value was then multiplied by 58 percent to determine TOC (Allison 1965). Inorganic carbon content was determined by treating 5.0 g of a soil subsample with 3 $\underline{N}$ HCl and then measuring the decrease in weight resulting from CO_2 loss (Allison, Bolles, and Moodie 1965).

Biochemical oxygen demand

25. Biochemical oxygen demand was determined with the following modifications for triplicate subsamples of each soil sample according to the procedures described in Standard Methods (APHA 1980). To each 300-mℓ standard BOD bottle was added either: (a) a 0.1-g subsample of soil, (b) a 0.1-g subsample of soil along with 5.0 mℓ of glucose-glutamic acid standard check solution, (c) 5.0 mℓ of glucose-glutamic acid standard check solution only, or (d) no soil or standard check solution. Following the filling of each bottle with dilution water and the stoppering of each bottle, a standard incubation and DO determination was carried out (APHA 1980). The BOD of individual soil samples was determined by difference between a given sample (a) and the reagent blank (d), and the results were extrapolated to milligrams of DO consumed by a gram of substrate in a litre of assay water.

Decomposition of vegetation

26. Decomposition of vegetation was studied using the following method. To 17 ℓ of distilled-deionized water in a Nalgene pipette washing jar were added 1.0 g of soil from Site 2 plus 17.0 g of vegetation. The vegetation had been composited in proportions representative of its original site, dried to constant weight at 80°C, and then ground in a Wiley Mill. Vegetation was kept suspended in the water column by a constant stream of air bubbles (30 mℓ/min) released from an airstone at the bottom of the column. Ten columns were set up to provide sufficient sample volume for the duration of the study. Each column was covered with a Nalgene cap containing holes for entrance and exit of air links. For each sampling interval, 700 mℓ of suspension was removed from each of the 10 jars and pooled into two replicate sets of 3500 mℓ each. These were then filtered or not filtered as described above and analyzed

for NH_4-N, nitrite-nitrate ($NO_2 + NO_3$ - N), TKN, total P, OPO_4-P, particulate and dissolved forms of organic carbon, TIC, BOD, and COD. Columns were incubated at 20°C, and samples were taken at 0, 5, 10, 25, and 50 days of incubation.

27. Appendix B presents a table indicating the parameters analyzed, analytical methods, detection limits, and units measured. Preservation techniques used were as specified previously. Samples were held in acid-washed linear polyethylene bottles until analyzed. Appendix C discusses quality control.

PART III: RESULTS

Soil Flooding Studies

28. Results obtained by repeat runs using the same soil sample
during these studies were reproducible; however, variations between
soils even in replicate samples from each study site were so great that
differences, if any, occurring between the three study sites were not
apparent. Thus, the water quality data are presented as averages of
results obtained with all six reaction chambers for one temperature.
While some of the results are displayed in tabular form, most are pre-
sented graphically. In the latter case, the variability observed in
the studies has been accounted for by averaging the standard deviations
through time for each study and dividing by the square root of the num-
ber of chambers (six) to give a mean standard error (M.S.E.) for each
study.* This will provide the reader with an idea of the variation
encountered in each study.

Soil characterization

29. The general physical and chemical properties of the soils are
presented in Tables 1-3. Several observations are apparent. First,
while soils from Sites 1 and 2 had similar particle-size distributions
(Table 3), Sites 1 and 3 had many similar physical and chemical proper-
ties. In general, Site 2 differs from both Sites 1 and 3 in nearly
every property tested (Tables 1-3). Second, each of these soils is rel-
atively rich in Fe and contains appreciable amounts of organic matter
and Mn, but each is also low in N and P content as well as in cation
exchange capacity (Table 3).

Dissolved oxygen

30. Changes in concentration of DO with time in reaction chamber
waters are presented for each test temperature in Figure 2. Aeration

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* Graphic data are presented as computer output plots. All points in
   Figures 2-15 are mean values of measurements from six reaction cham-
   bers. All points in Figures 16-21 are mean values of three runs,
   each conducted in duplicate. For all figures, the M.S.E. is averaged
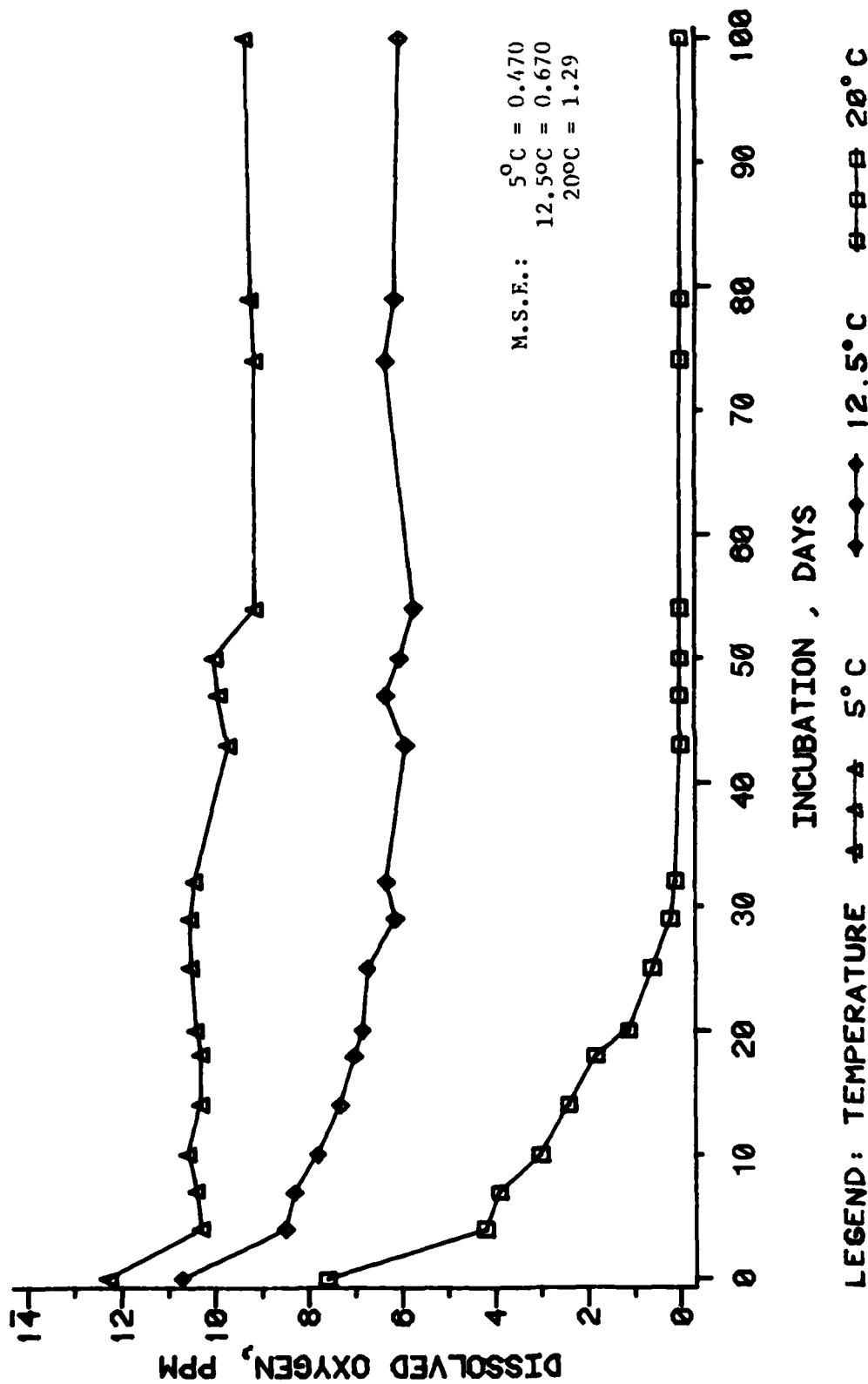   across the entire incubation period for each curve shown.

Figure 2. Changes in DO concentration in water columns of the reactor units during 100-day incubation period. DO saturation levels: 5°C = mg/ℓ, 12.5°C = 10.7 mg/ℓ, and 20°C = 9.2 mg/ℓ

M.S.E.:
5°C = 0.470
12.5°C = 0.670
20°C = 1.29

LEGEND: TEMPERATURE ▲—▲—▲ 5°C   ◆—◆—◆ 12.5°C   ▣—▣—▣ 20°C

DISSOLVED OXYGEN, PPM

INCUBATION, DAYS

was terminated in each of the units on day 0 of the incubation period, but DO was continuously added to each unit with inflow waters (inflow rate = 9.8 ℓ/day/unit with the DO concentration at saturation for each temperature examined; an equivalent of 90.2 mg of DO/day was added to each unit at 20°C).

31. At 20°C, oxygen demand was strong enough to remove all DO from the water column within 30 to 40 days. Dissolved oxygen was not completely depleted from the water columns in the 5° and 12.5°C studies; however, some depletion did occur, and this was intense enough to drop and hold DO levels to 3.6 and 4.6 mg/ℓ below saturation, respectively (Figure 2). Regression analysis of the three DO curves in Figure 2 yielded depletion rates of 0.017, 0.023, and 0.185 mg/ℓ/day at 5°, 12.5°, and 20°C, respectively (depletion rates are slopes of linear regressions run on each of the curves in Figure 2). These translate into oxygen demands of 16.8, 22.7, and 183 mg DO/m^2 of soil surface/day at the same temperatures.

Biochemical oxygen demand

32. Materials having a high 5-day 20°C BOD, when released from newly flooded soils in an impoundment, constitute an important source of oxygen depletion in downstream areas. For the three temperatures examined in this study, the mean steady-state concentrations of BOD-producing materials were 2.16 ± 0.750, 1.60 ± 0.350, and 1.10 ± 0.308 mg/ℓ at 5°, 12.5°, and 20°C, respectively.* These are equivalent to release rates of 72.5, 53.7, and 37.0 mg/m^2 soil surface/day at the three temperatures. The BOD release rates and DO depletion rates ran counter to each other with respect to temperature, suggesting that lower temperatures preserved the integrity of BOD-producing substances, possibly by causing a decrease in the activity of organisms consuming them, while the opposite occurred at higher temperatures.

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* These releases were chosen as steady-state because there were no trends towards increasing or decreasing concentrations over the entire course of the study relative to the amount initially present. Moreover, reflooding the 20°C soils in a rerun yielded similar concentrations.

Chemical oxygen demand

33. Both total (unfiltered) and dissolved (passed through a 0.45-μm membrane filter) COD were measured. No detectable differences were found between the two COD determinations at any temperature, indicating that all COD detectable in the water column was present in the dissolved form. Values obtained for COD are presented in Figure 3. Apparently, the largest amount of this material was released at 12.5°C; however, the patterns of release at all temperatures were irregular and showed no relationship to DO or any other parameter.

Carbon

34. Changes in TIC and TOC are given in Figures 4 and 5, respectively. The dissolved forms of these parameters were also analyzed; no significant differences between the two methods were found for either form of carbon, indicating that all detectable TIC and TOC were present in the dissolved form.

35. Examination of Figure 4 reveals three important facts. First, while there was a general increase in TIC between the start and the completion of incubation in each of the studies, TIC levels in the 5° and 12.5°C studies were of a similar magnitude while levels at 20°C were much higher. Second, TIC concentrations stabilized after 50 days of incubation in the range of 9 to 12 mg/ℓ in both the 5° and 12.5°C studies. Third, and, in contrast, TIC levels observed during the 20°C study climbed well above those at 5° and 12.5°C, with accumulation becoming very rapid after 30 to 40 days when water in the 20°C reaction chambers became anoxic.

36. Releases of TOC were erratic (Figure 5). The lowest values and the most steady release pattern occurred at 5°C, while the largest values and the most irregular release pattern occurred at 20°C. Interestingly, TOC levels initially decreased after the onset of anoxia at 20°C; this may have resulted from the removal of TOC via methanogenesis, and is supported by the occurrence of methane accumulation in reaction chamber headspaces during the anoxic period. However, the accumulation of TOC after 50 days was not accompanied by an observed decrease in the rate of methanogenesis. Release of TOC at 12.5°C was more erratic than
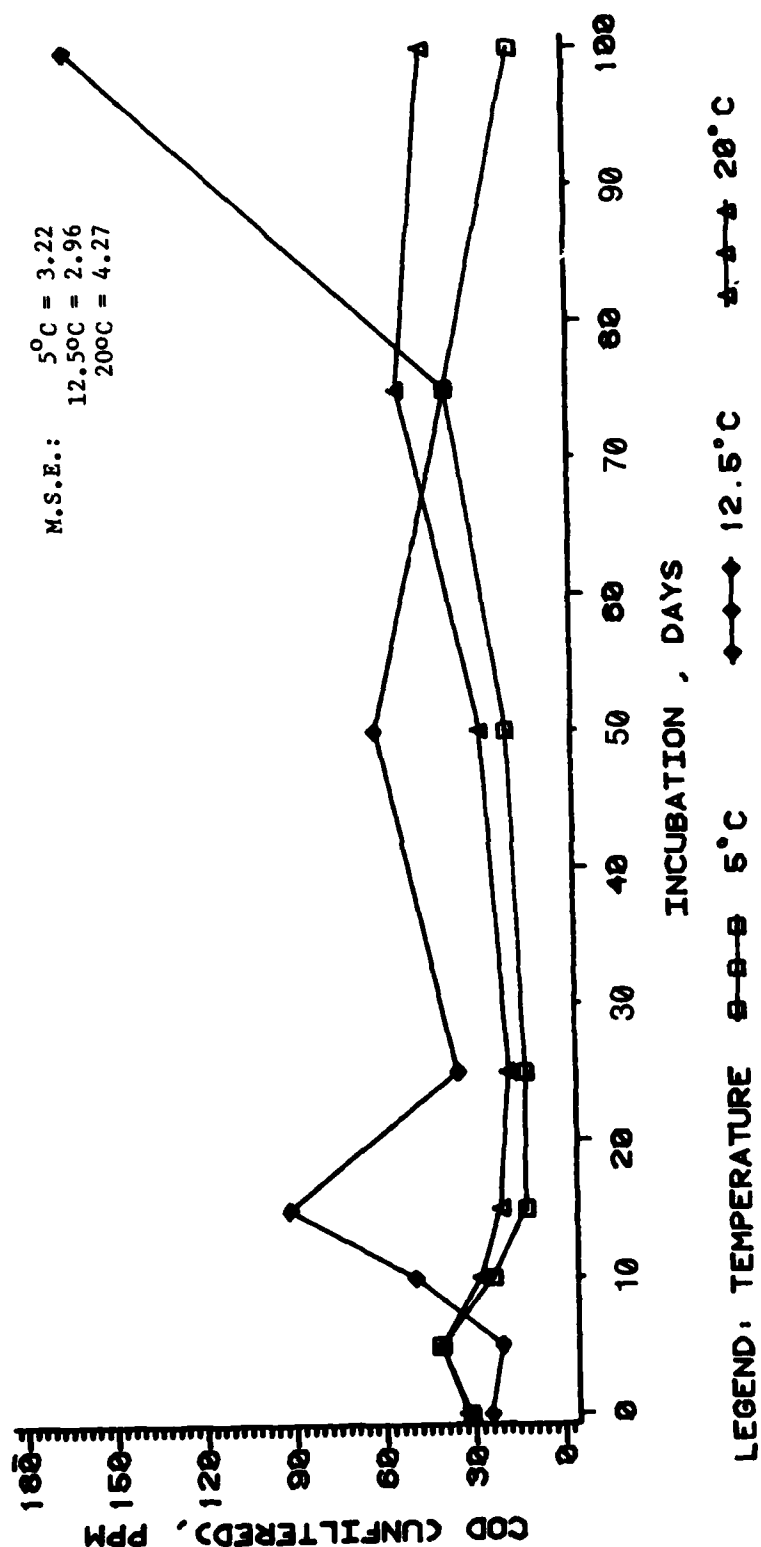
17

M.S.E.: $5^\circ C = 3.22$
$12.5^\circ C = 2.96$
$20^\circ C = 4.27$

COD (UNFILTERED), PPM

INCUBATION , DAYS

LEGEND: TEMPERATURE ▣—▣—▣ 5°C ◆—◆—◆ 12.5°C ▲—▲—▲ 20°C

Figure 3. Changes in COD concentration in water columns of the reactor units during 100-day incubation period
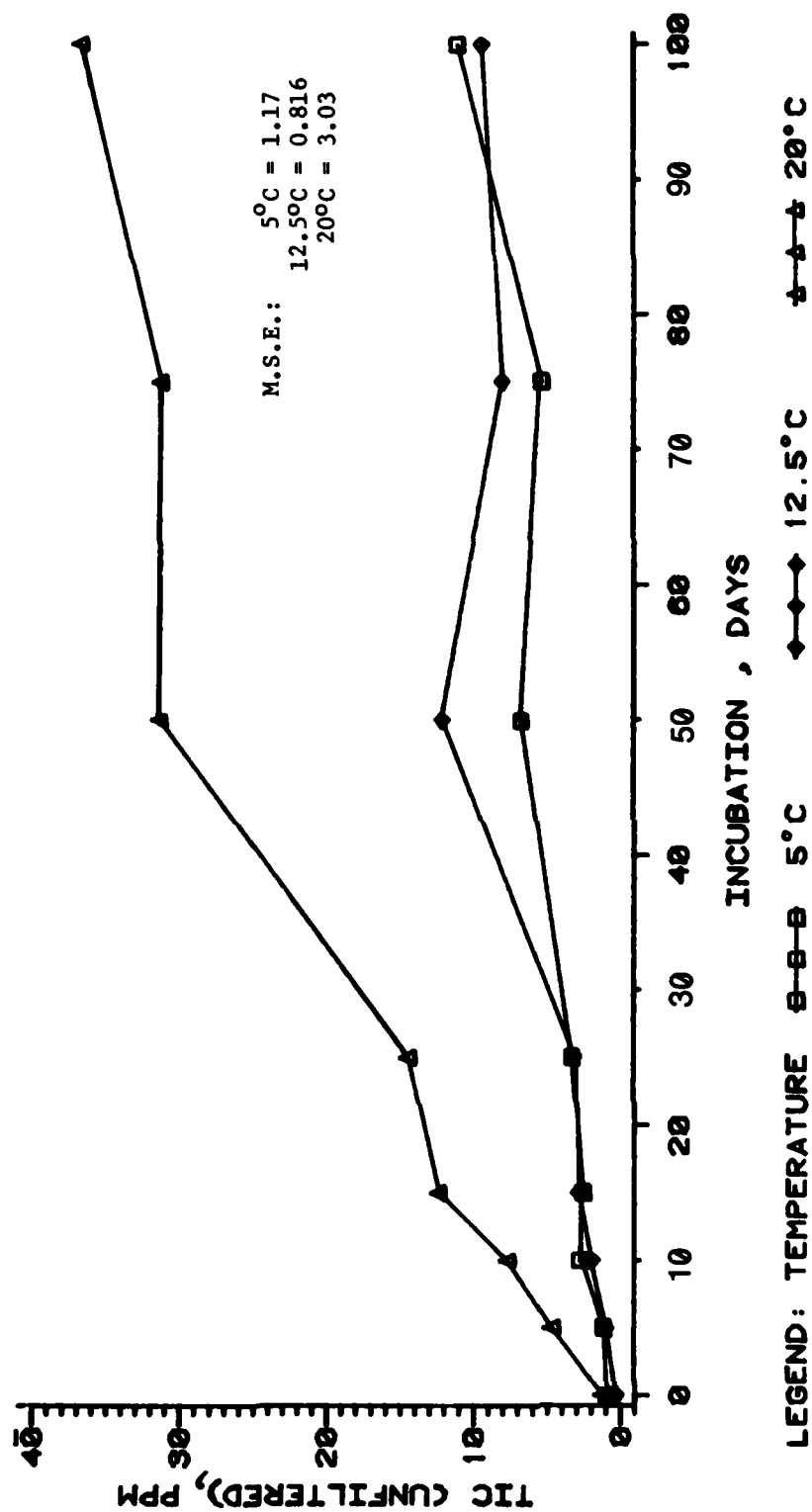
18

Figure 4. Changes in TIC concentration in water columns of the reactor units during 100-day incubation period
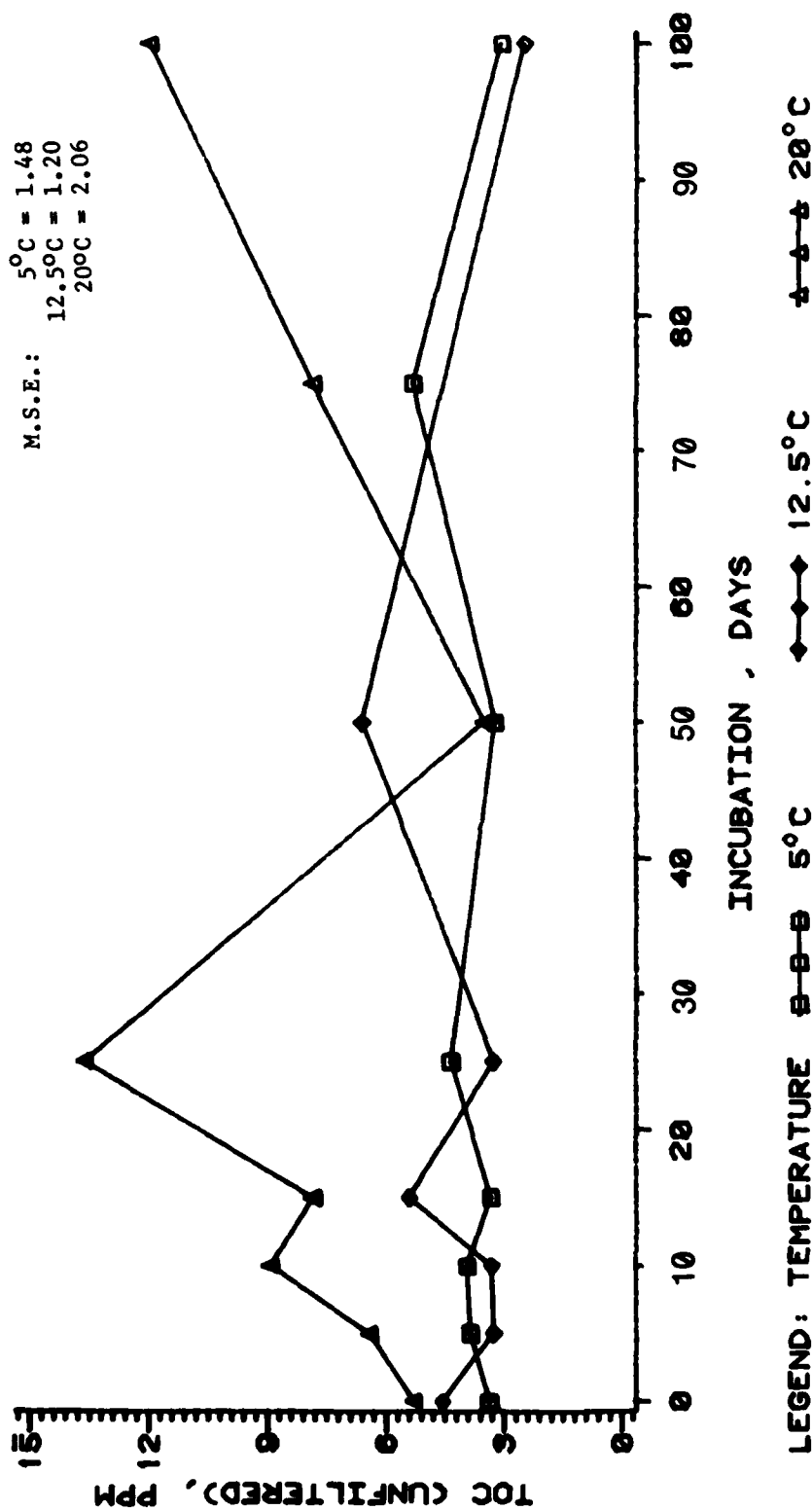
19

Figure 5. Changes in TOC concentration in water columns of the reactor units during 100-day incubation period

LEGEND: TEMPERATURE �□─�□─�□ 5°C ◆─◆─◆ 12.5°C ▲─▲─▲ 20°C

M.S.E.: 5°C = 1.48
12.5°C = 1.20
20°C = 2.06

20

at 5°C and, on occasion, release levels exceeded those found at 20°C. While outflows served as a mechanism for removal of TOC at all three temperatures, methanogenesis was not observed at 5° or 12.5°C.

Nitrogen

37. Three forms of soluble N plus one form of particulate N were monitored throughout the incubation period: NH_4-N, $NO_3 + NO_2$ - N, and particulate plus dissolved TKN. As with COD, there was no apparent difference between dissolved (filtered) and total (dissolved plus particulate-unfiltered) TKN, indicating that most of the TKN detected was dissolved (Figure 6). Remarkably, TKN values for the three different temperatures remained at approximately the same value until the time at which chambers in the 20°C study became anoxic (30-40 days). At this point, TKN began to accumulate in the 20°C reactor units, while remaining nearly constant in the 5° and 12.5°C reactor units.

38. A similar trend was observed for NH_4-N (Figure 7). In this case, accumulation of ammonium began within the first 10 days at 20°C, but remained at or near the detection limits at 5° and 12.5°C. Since TKN consists of ammonium plus organic nitrogen, it was concluded that most of the TKN released at 5° and 12.5°C was organic.

39. The $NO_3 + NO_2$ - N behaved quite differently from the other forms studied (Figure 8). Here, maximum levels were achieved at 12.5°C; apparently this was a result of the combination of active nitrification of nitrogenous materials released from the soils and the low denitrification rate. By contrast, at 5°C, only small amounts of $NO_3 + NO_2$ - N accumulated, and these were nearly depleted after half the incubation period. At 20°C, active denitrification and nitrate reduction occurred, removing $NO_3 + NO_2$ - N rapidly and causing accumulation of nitrogen gas in the reaction chamber headspace.

Phosphorus

40. Release patterns for total phosphorus (TP) and OPO_4-P are presented in Figures 9 and 10, respectively. Total phosphorus was released at all three temperatures (Figure 9); however, since there were no accumulations of OPO_4-P at 5° and 12.5°C (Figure 10), it was concluded that the TP released at these temperatures was mainly organic.

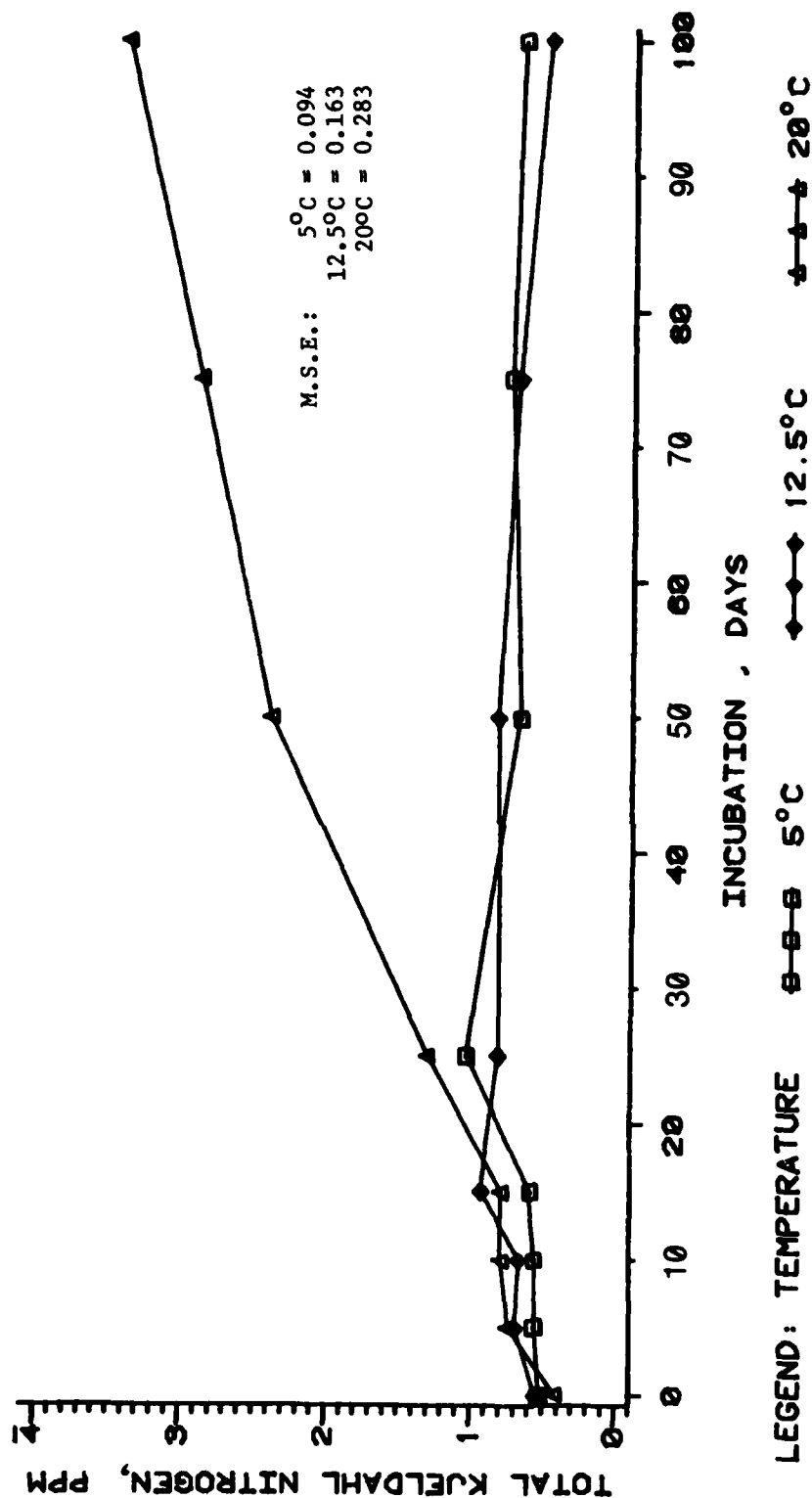Figure 6. Changes in TKN concentration in water columns of the reactor units during 100-day incubation period

LEGEND: TEMPERATURE: ⊟—⊟—⊟ 5°C   ◆—◆—◆ 12.5°C   ▲—▲—▲ 20°C

M.S.E.: 5°C = 0.094
        12.5°C = 0.163
        20°C = 0.283

22

Figure 7. Changes in NH_4-N concentration in water columns of the reactor units during 100-day incubation period

LEGEND: TEMPERATURE □—□—□ 5°C ◆—◆—◆ 12.5°C ▲—▲—▲ 20°C

M.S.E.: 5°C = 0.027
12.5°C = 0.098
20°C = 0.226

AMMONIUM-N, PPM

INCUBATION, DAYS

23

LEGEND: TEMPERATURE □—□—□ 5°C ◆—◆—◆ 12.5°C ▲—▲—▲ 20°C

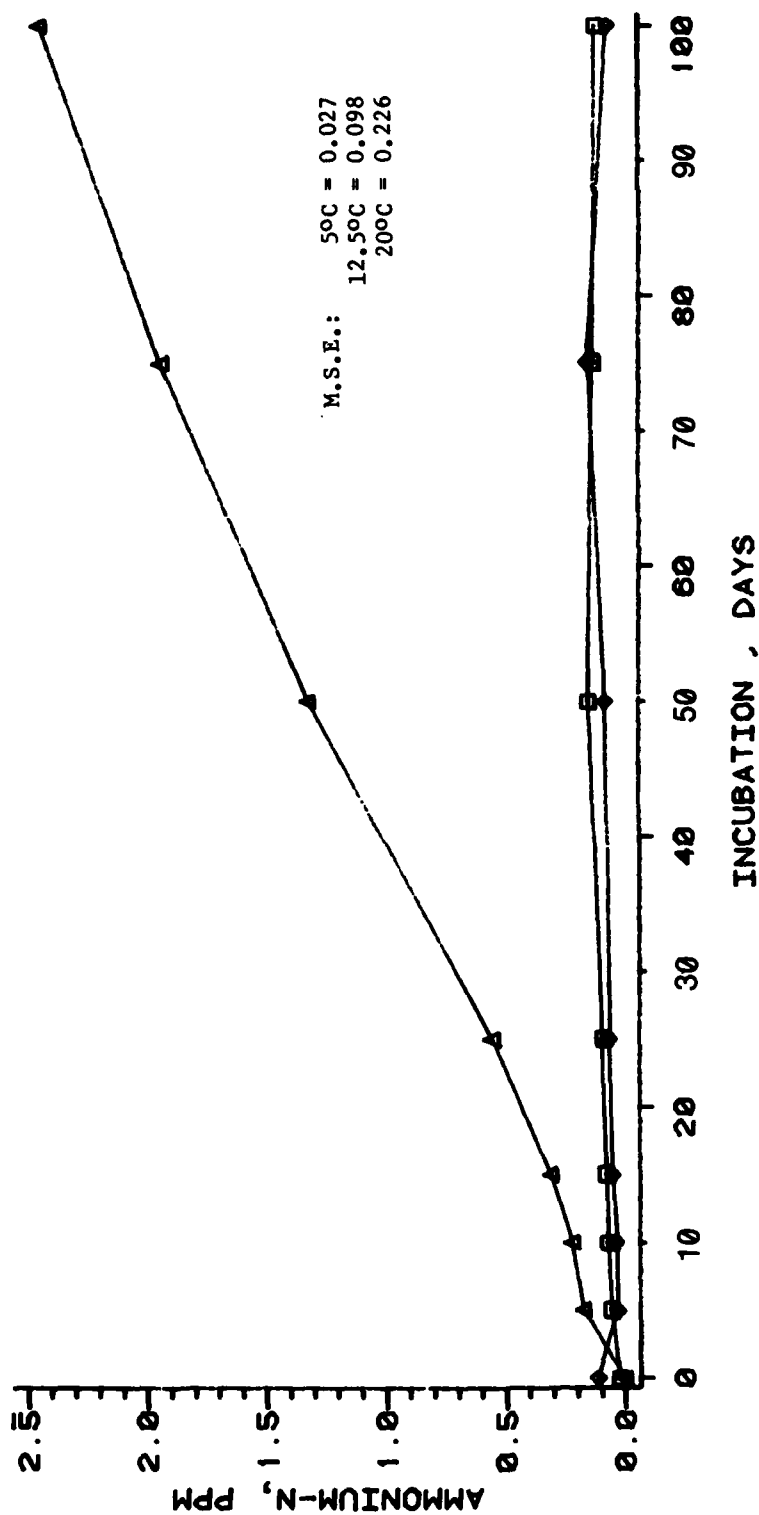M.S.E.: 5°C = 0.084
        12.5°C = 0.322
        20°C = 0.029

Figure 8. Changes in $NO_3 + NO_2 - N$ concentration in water columns of the reactor units during 100-day incubation period

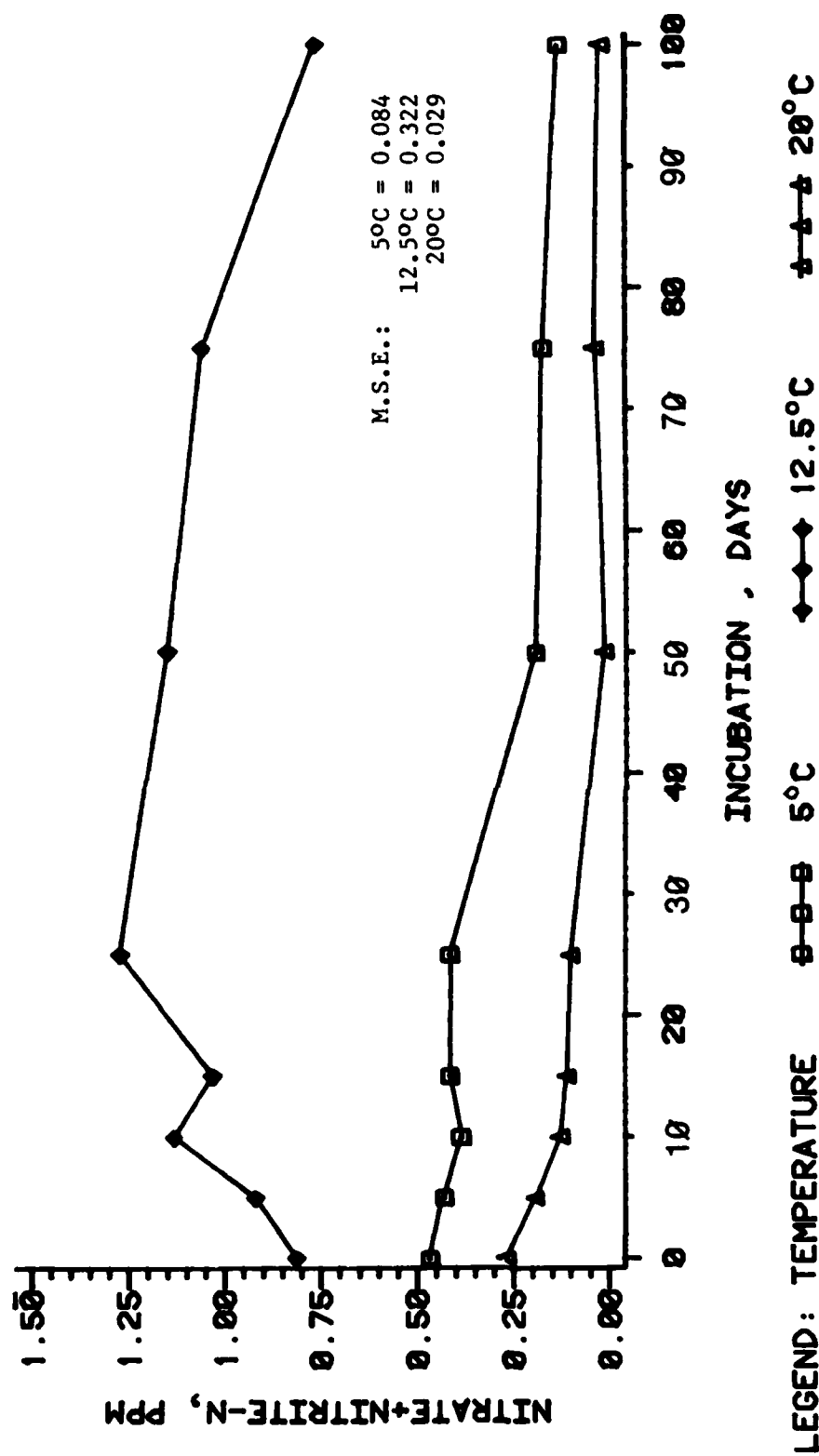Figure 9. Changes in TP concentration in water columns of the reactor units during 100-day incubation period

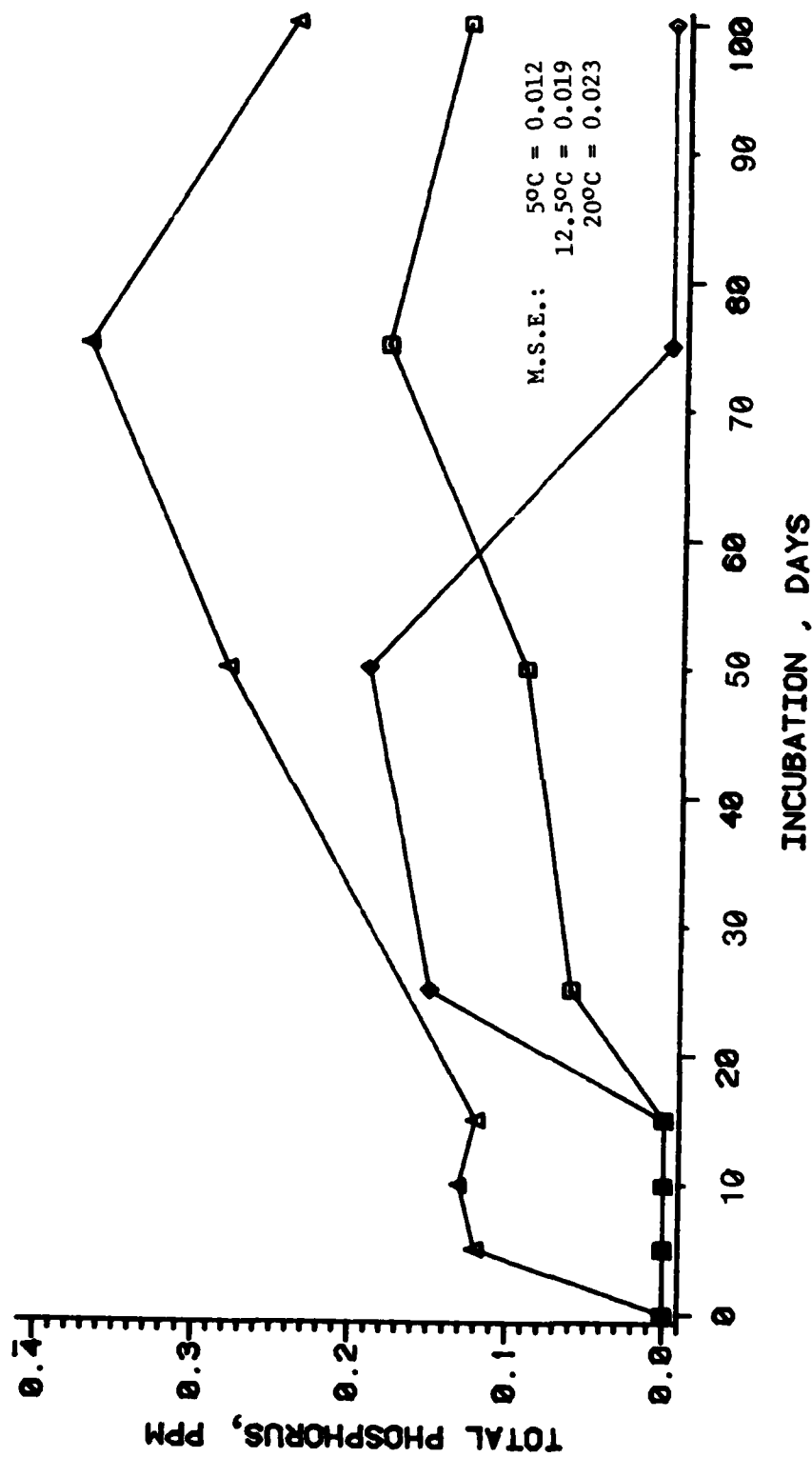LEGEND: TEMPERATURE □—□—□ 5°C ◆—◆—◆ 12.5°C △—△—△ 20°C
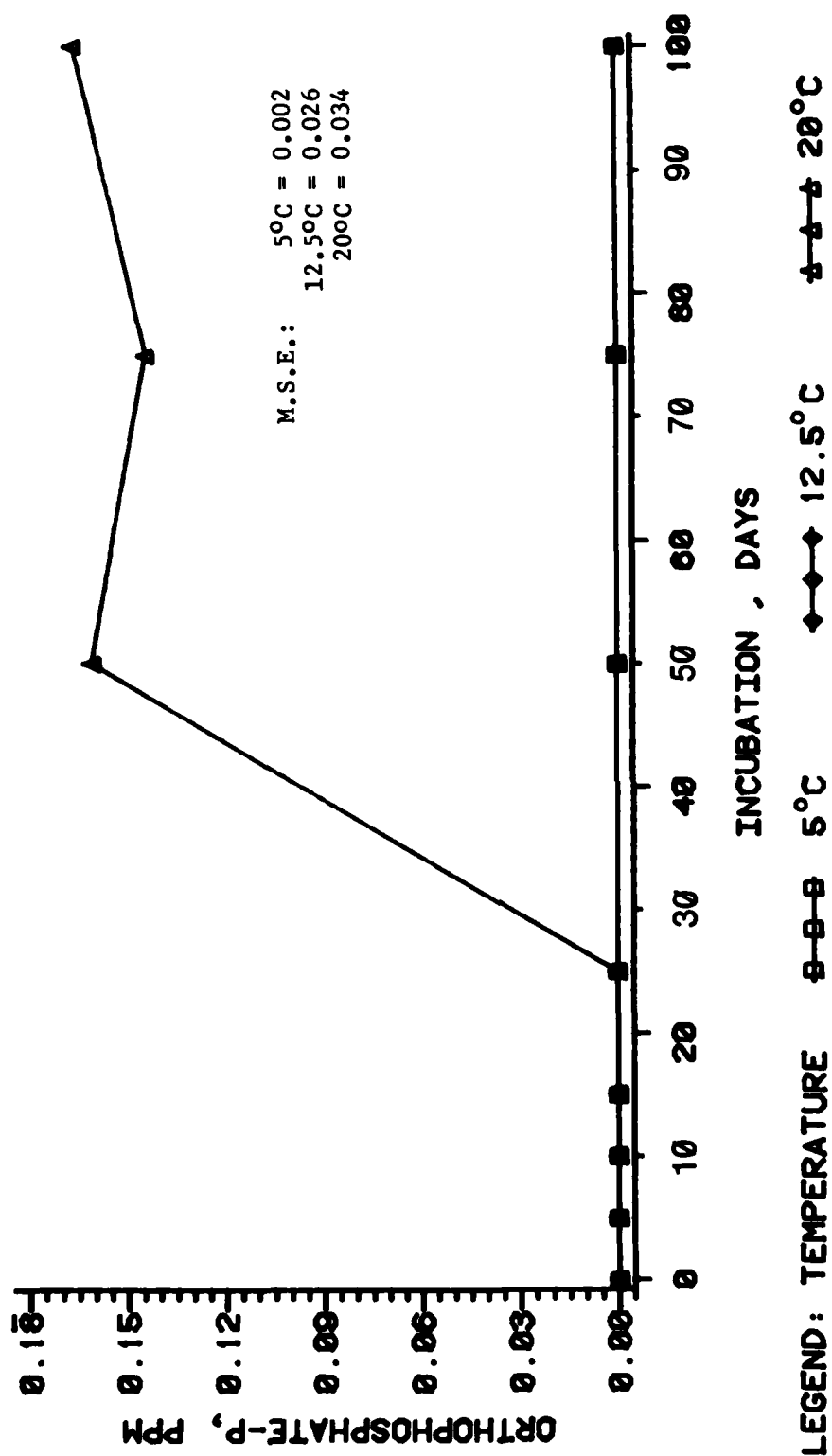
M.S.E.: 5°C = 0.012
12.5°C = 0.019
20°C = 0.023

Figure 10. Changes in OPO_4-P concentration in water columns of the reactor units during 100-day incubation period

At 20°C, nearly one half of the TP accumulated after 25 days was in form of OPO_4-P (Figures 9 and 10). As with the other total parameters considered thus far, there was no significant difference between filtered and unfiltered TP, indicating that all TP was in the dissolved form.

Sulfur

41. Although inflow concentrations of SO_4 were maintained at nearly steady concentrations of approximately 9.64 mg/ℓ (as $CuSO_4$, see paragraph 10), levels in the 5° and 20°C reactor units generally ran well above this (Figure 11). The SO_4 decreased below the limits of detection in the 20°C reaction chambers at approximately the onset of anoxia (30-40 days), and this was subsequently followed by the appearance of sulfide, according to the following schedule:

Incubation days	Sulfide Concentration mg/ℓ
0	0
28	0.025
62	0.062
75	0.290
85	0.048
100	0.046

M.S.E. = 0.027

42. The appearance of a black precipitate in the 20°C chambers shortly after the sulfide maximum concentration at 75 days was probably the result of ferrous sulfide formation with consequent precipitation of sulfide from the water column.

43. Concentrations of SO_4 in the 12.5°C study remained slightly above the inflow level (Figure 11). Apparently, after 25 days of incubation, the soil released sulfide at a rate which only slightly exceeded the removal rate.

Iron and manganese

44. Iron followed the expected release pattern: no release under aerobic conditions, but some release during anoxia (Figure 12). Thus,

27
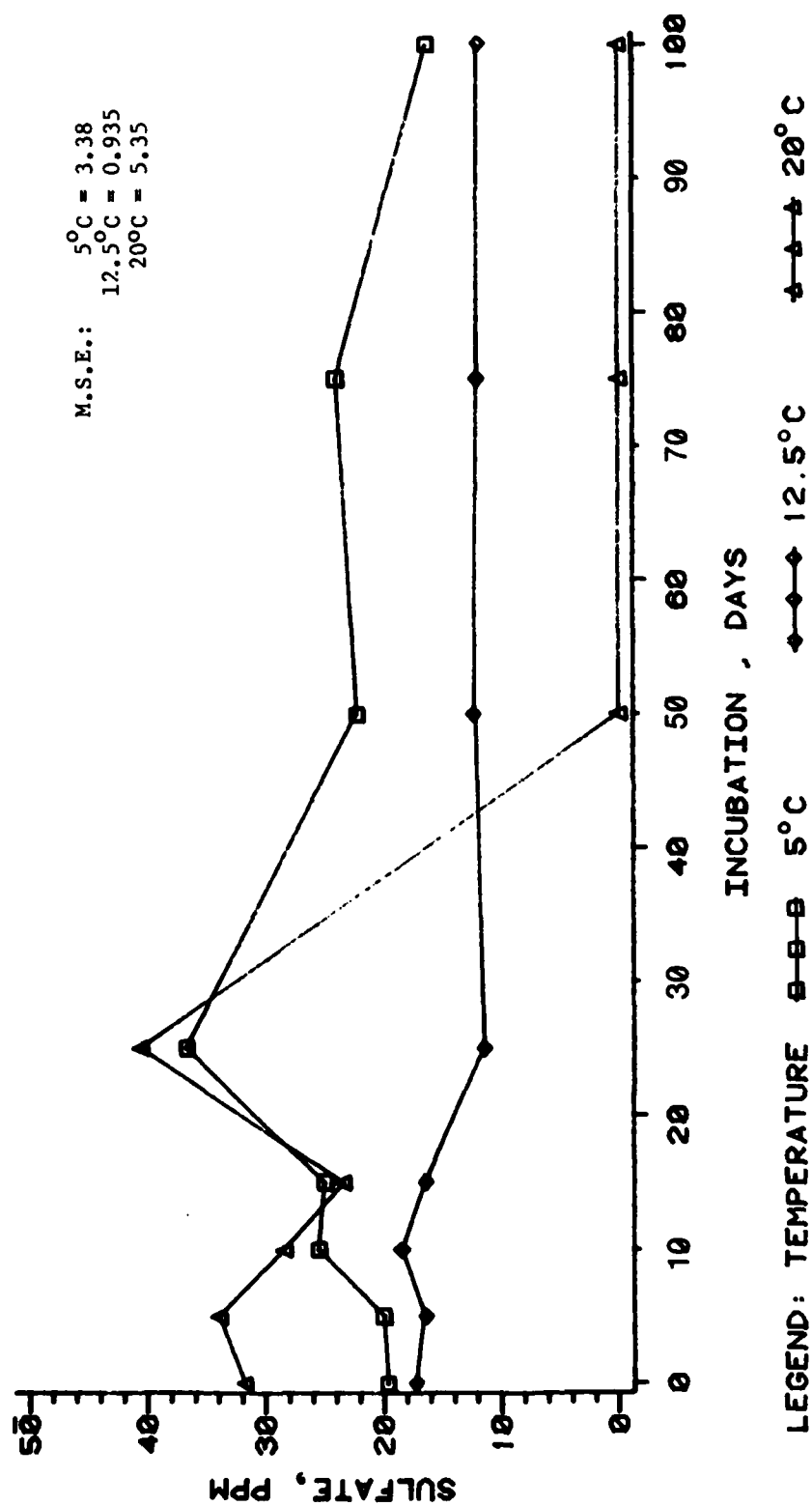
Figure 11. Changes in SO_4 concentration in water columns of the reactor units during 100-day incubation period

LEGEND: TEMPERATURE □—□—□ 5°C ◆—◆—◆ 12.5°C ▲—▲—▲ 20°C

M.S.E.:
5°C = 3.38
12.5°C = 0.935
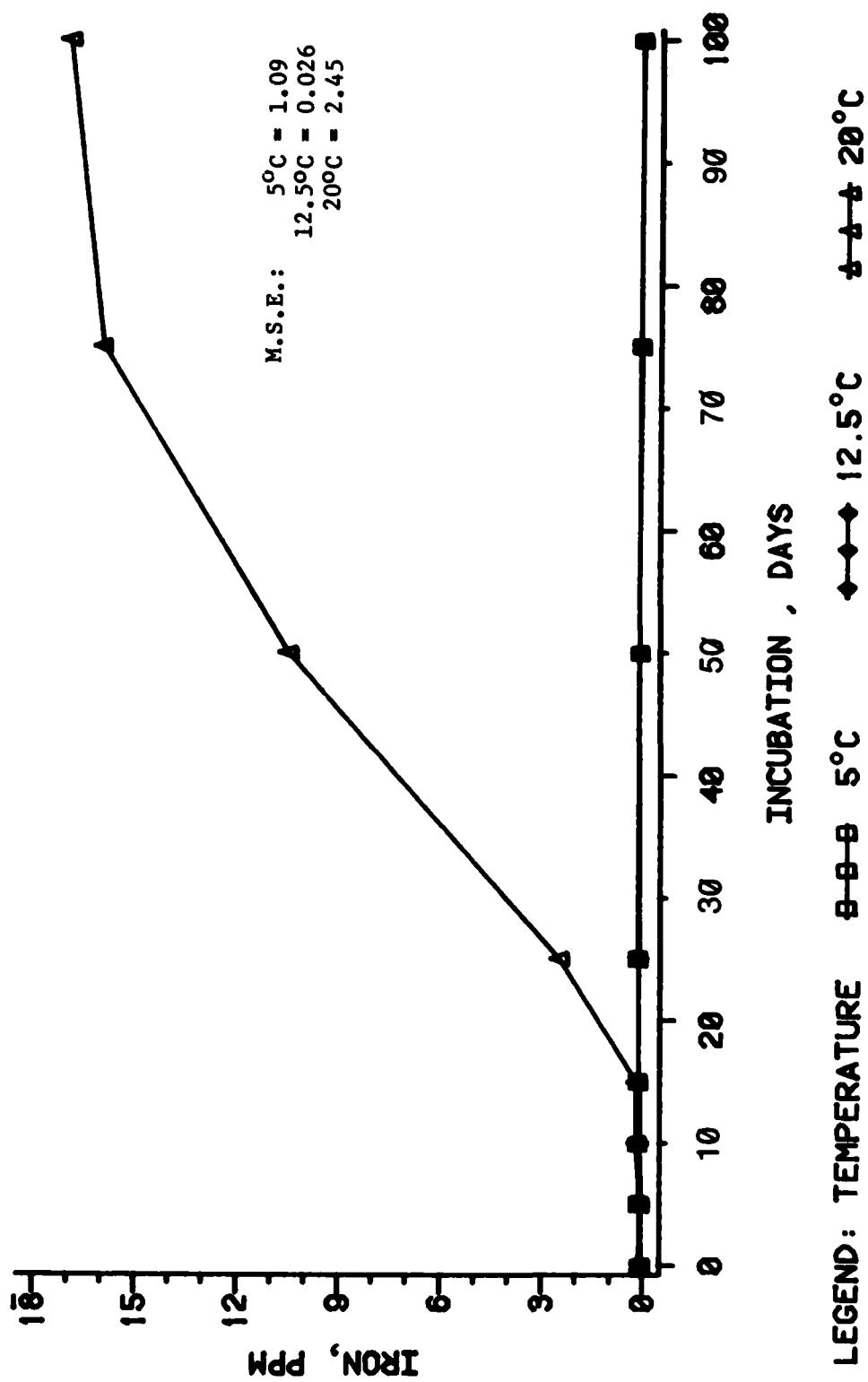20°C = 5.35

INCUBATION , DAYS

SULFATE, PPM

28

Figure 12. Changes in Fe concentration in water columns of the reactor units during 100-day incubation period

only the 20°C study resulted in the accumulation of Fe in the overlying water (Figure 12). Accumulation in this study was further indicated by the formation of black ferrous sulfide precipitate after 75 days of incubation and by the production of red iron oxyhydroxide upon initiation of reaeration of water in the 20°C chambers after 120 days of incubation.

45. Manganese was also released in significant quantities in the 20°C study (Figure 13). However, small concentrations of Mn were also released at 5°C; apparently, conditions in the flooded soil at this temperature became sufficiently reducing to permit formation of soluble manganous Mn which, unlike Fe, is only very slowly oxidized in the presence of DO, thus permitting release of some reduced Mn into the water column.

Color

46. The results of a 1-week aerobic extraction of soils with water gave the following values for color:

    a. Wavelength of maximum absorption: 610 nm

    b. Hue: Orange red

    c. Percent luminosity: 98.4

A comparison of the changes in quality or intensity of color that occur in water during sequential floodings is not presented in detail herein. However, as soils in this study aged during flooding, the wavelength of maximum absorption shifted to 540 nm, equivalent to a hue of greenish yellow.

pH

47. Figure 14 presents the changes in pH with time for the three temperatures. There was virtually no difference between the slightly acidic pH ranges for the 5° and 12.5°C studies, but these were significantly lower than the 20°C study; the latter pH remained much closer to neutrality.

Conductivity

48. Figure 15 gives data on changes in conductivity in the water column over time during the three studies. As with pH, conductivity in the 5° and 12.5°C studies was constant while the level at 20°C was significantly increased. Also of interest is the observation that the

Figure 13. Changes in Mn concentration in water columns of the reactor units during 100-day incubation period

31

Figure 14. Changes in pH in water columns of the reactor units during 100-day incubation period

LEGEND: TEMPERATURE □—□—□ 5°C ◆—◆—◆ 12.5°C △—△—△ 20°C

M.S.E.: 5°C = 0.143
12.5°C = 0.108
20°C = 0.076

32

CONDUCTIVITY, µMHOS/CM

INCUBATION , DAYS

M.S.E.: 5°C = 0.954
12.5°C = 2.47
20°C = 8.75

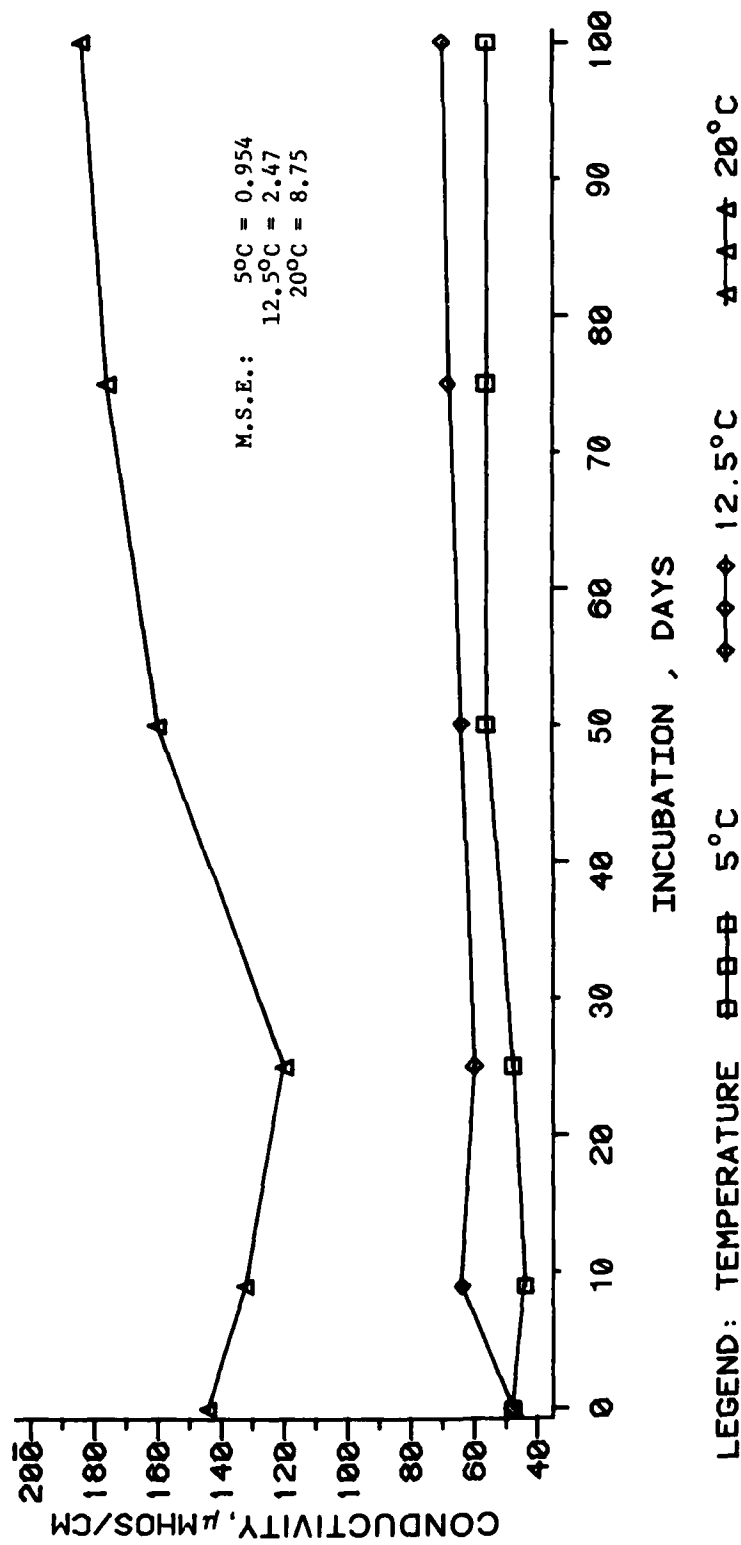LEGEND: TEMPERATURE ⊟⊟⊟ 5°C ◆◆◆ 12.5°C △△△ 20°C

Figure 15. Changes in conductivity in water columns of the reactor units during 100-day incubation period

33

largest change in conductivity occurred at 20°C after the waters became anoxic.

Vegetative Decomposition Studies

49. Results obtained during the vegetative decomposition studies were reproducible and were much less variable than those observed in the soil flooding studies. This is probably a result of the homogeneous composition of the vegetation originating from the drying and grinding procedures used in its preparation. While drying and grinding of vegetation are controversial according to some authors (Sylvester and Seabloom 1965), this procedure does offer the advantage of providing a uniform substrate which in turn permits comparison between rate and extent of decomposition among vegetative samples from various locations. Such treatment also maximized the rate of decomposition by increasing the surface area available for leaching and microbial attack (Alexander 1977); this permits use of the resulting data for a worst-case estimate. Because the rate of decomposition of intact vegetation varies according to the size and integrity of the vegetation, it is not possible to provide an exact estimate of how much the grinding processes accelerate the rate of decomposition. Since no difference was observed in the results between the types of vegetation used (whether pine or a 50/50 pine-hardwood mixture), all data were averaged.

Dissolved oxygen

50. Dissolved oxygen was maintained at saturation in all vegetative decomposition studies. However, because all oxygen demand created by the presence of vegetation was biological and not the result of demand created by oxidation of reduced chemical species, BOD should be comparable to DO demand.

Biochemical oxygen demand

51. Unlike the soils studies, the vegetation did not exert a steady oxygen demand; rather, soluble (filtered) BOD decreased as the vegetation aged and decomposition proceeded (Figure 16). Thus, the initial BOD level was approximately 8 mg/ℓ and declined at a rate of

34

M.S.E.: BOD = 1.08
COD = 4.84

INCUBATION , DAYS

LEGEND: DEMAND ⊟–⊟–⊟ BOD ◆–◆–◆ COD
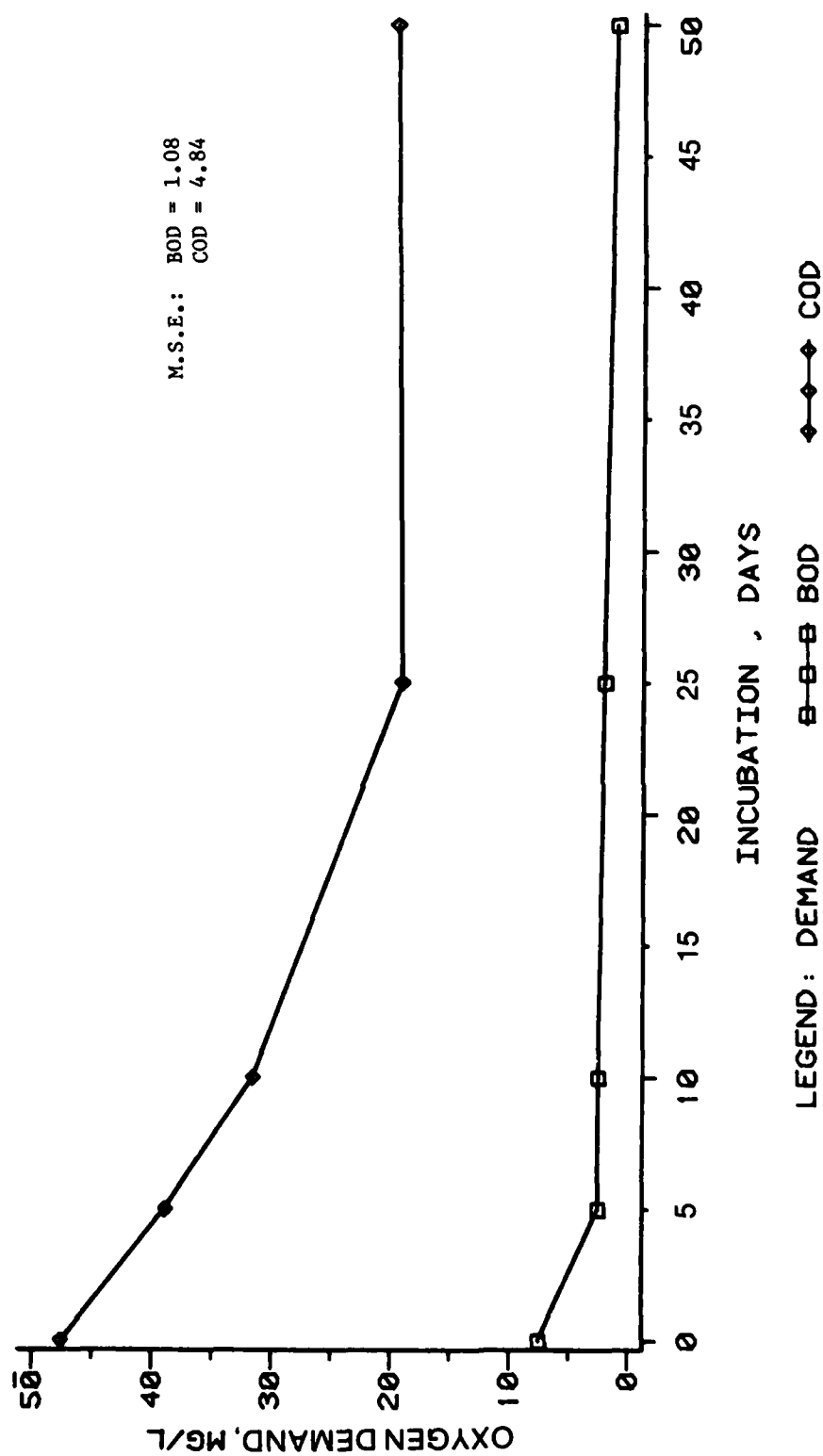
OXYGEN DEMAND, MG/L

Figure 16. Changes in soluble BOD and COD in water columns of decomposition reactors during 50-day incubation period

35

0.097 mg/ℓ per day, approaching 0.92 mg/ℓ at day 50. Most of the BOD observed in the first 5 days probably resulted from readily soluble, fairly simple substances lost from the vegetation upon initial flooding. After the first 5 days, most of the remaining materials were more refractory to microbial attack.

Chemical oxygen demand

52. Because measurement of total (dissolved plus particulate) COD would have produced erratic results, only filtered (dissolved) COD was measured. As depicted in Figure 16, COD greatly exceeded BOD over the entire 50-day period of incubation. This was not unexpected since a great many materials liberated by decompositional processes may themselves be slightly or highly refractory to biological attack (i.e., tannins, lignins, polyphenols). Interestingly, BOD decreased by 88.1 percent during the 50-day incubation while COD decreased 58.9 percent. At the same time, BOD decreased from an initial 16.2 percent of the COD present at time 0 to 4.72 percent of the COD present at 50 days, indicating that the biological availability of the COD decreased nearly fourfold while the amount of COD itself decreased slightly more than half. This, however, ignores the fact that such phenomena as surface adsorption and incorporation of oxygen-demanding substances into microbial cells may have been very important in changing the BOD:COD ratio.

Carbon

53. Data on both dissolved and particulate forms of inorganic and organic carbon are presented in Figures 17 and 18. Both DOC and particulate organic carbon (POC) far exceeded the concentrations of dissolved inorganic carbon (DIC) and particulate inorganic carbon (PIC). In each category, the dissolved form exceeded the concentration of the particulate form by twofold to fivefold. Interestingly, while the concentration of DOC steadily decreased throughout the incubation, the level of DIC increased. The small increase in DIC observed may have been prevented from becoming larger because the sparging action of aeration can strip dissolved gases from solution. Another point to be considered here is that the concentration of DOC is well below that of COD; in fact, the former more closely approaches that of BOD.
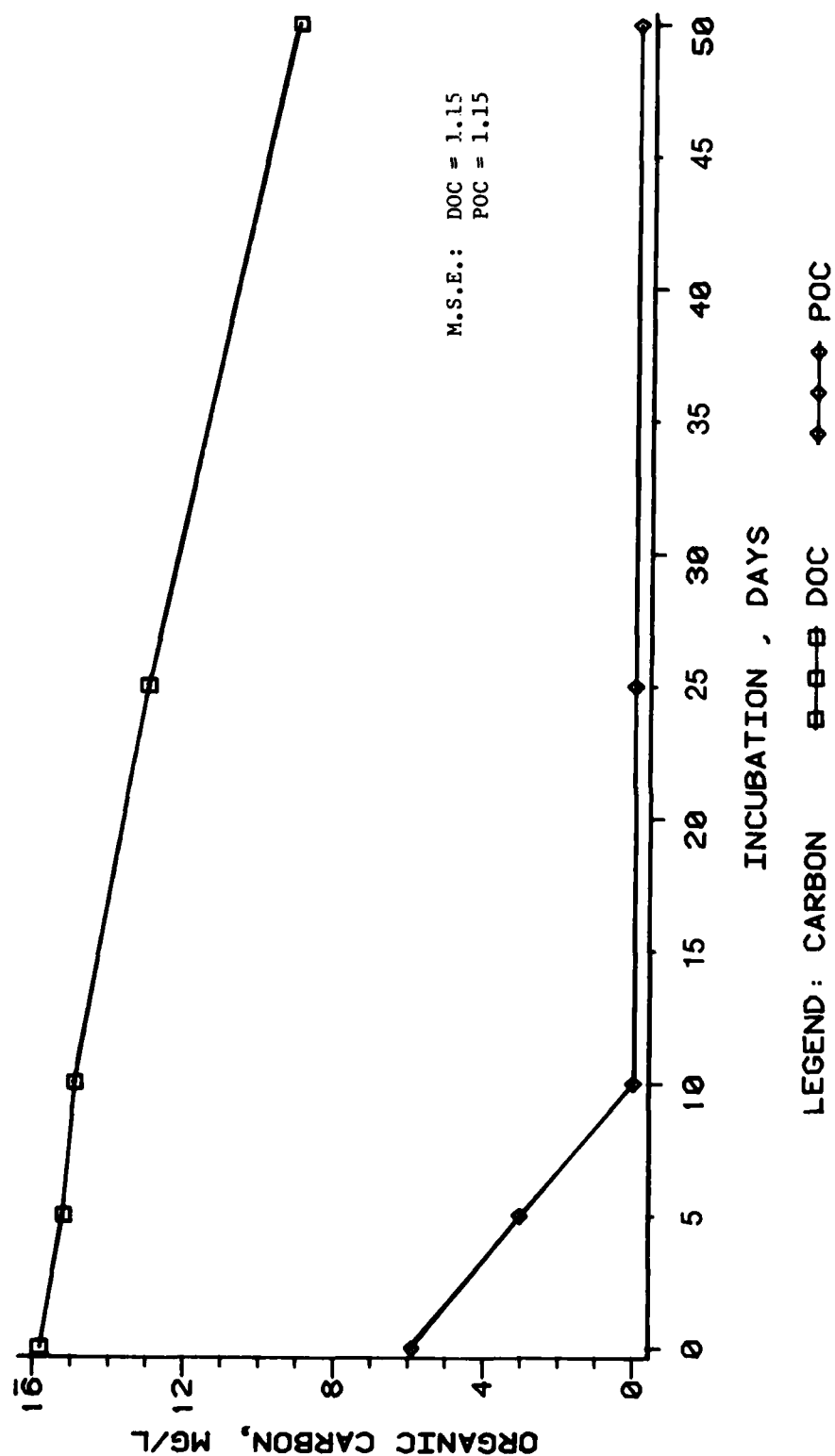
36

Figure 17. Changes in DOC and POC in water columns of decomposition reactors during 50-day incubation period
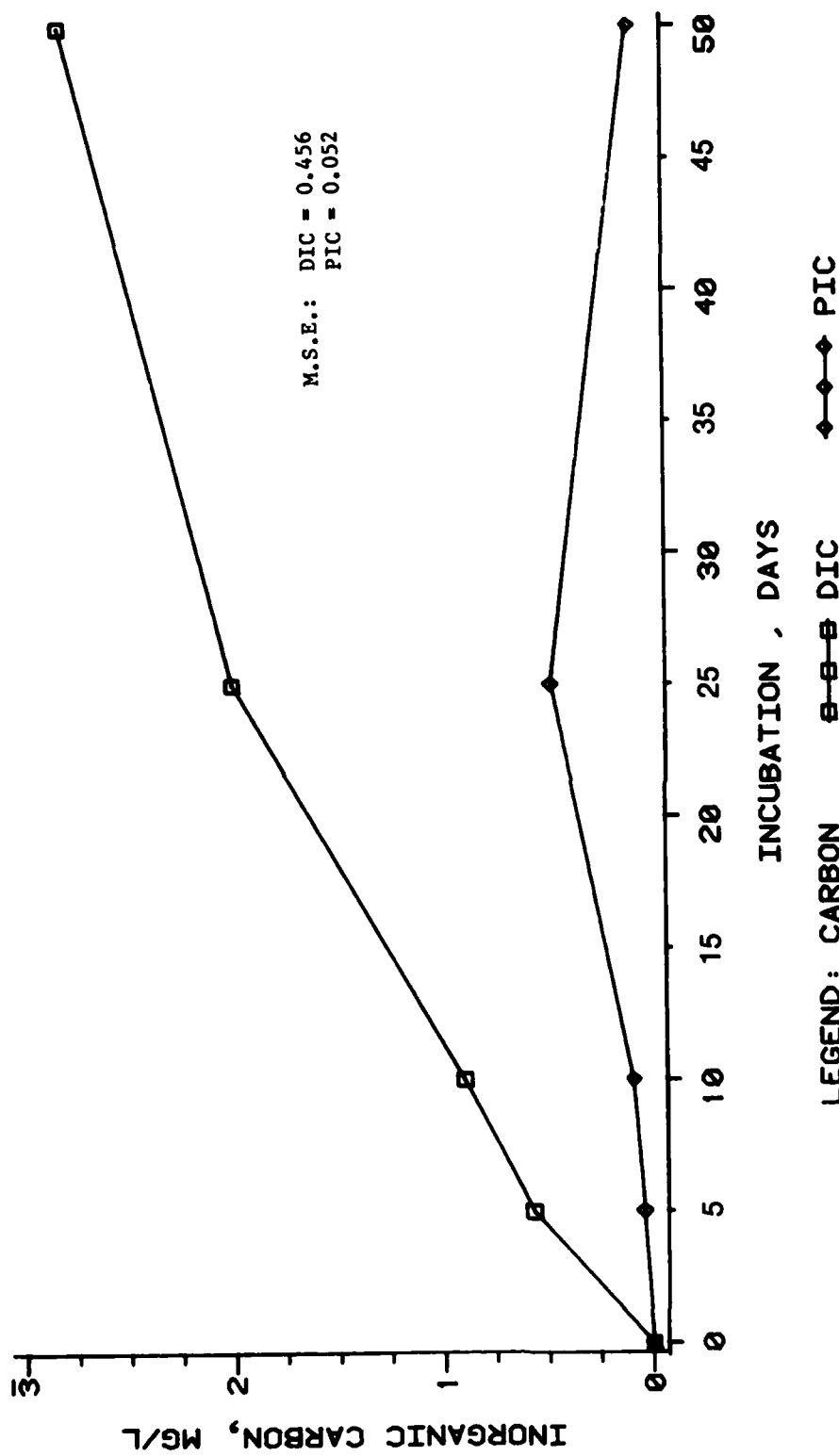
37

Figure 18. Changes in DIC and PIC in water columns of decomposition reactors during 50-day incubation period

Nitrogen

54. The release patterns of the organic and inorganic forms of nitrogen examined in this study are depicted in Figure 19. Release of TKN occurred immediately with the highest level being present on day 0. Ammonium concentration remained considerably below TKN with barely observable changes over the course of incubation. Surprisingly, the NO_3 - NO_2 - N concentration remained below that of NH_4-N even though these studies were conducted in a mixed aerobic system. However, low nitrification rates (oxidation of ammonium to nitrite and nitrate) are common in systems having low concentrations of soil or sediments that serve as sources of nitrifiers to carry out this process.

Phosphorus

55. Figure 20 shows the results of determination of TP and OPO_4-P for the vegetation decomposition study. As indicated, most of the TP released was in the form of OPO_4-P, so little of the TP was composed of organic P.

Sulfur

56. Sulfate-sulfur remained below the 8-mg/ℓ detection limit for the entire 50-day incubation period in each decomposition study.

Iron and manganese

57. Only minimal amounts of Fe and Mn appeared in solution during the 50-day incubation period. The largest concentration reached by both metals was 0.10 mg/ℓ (Figure 21).
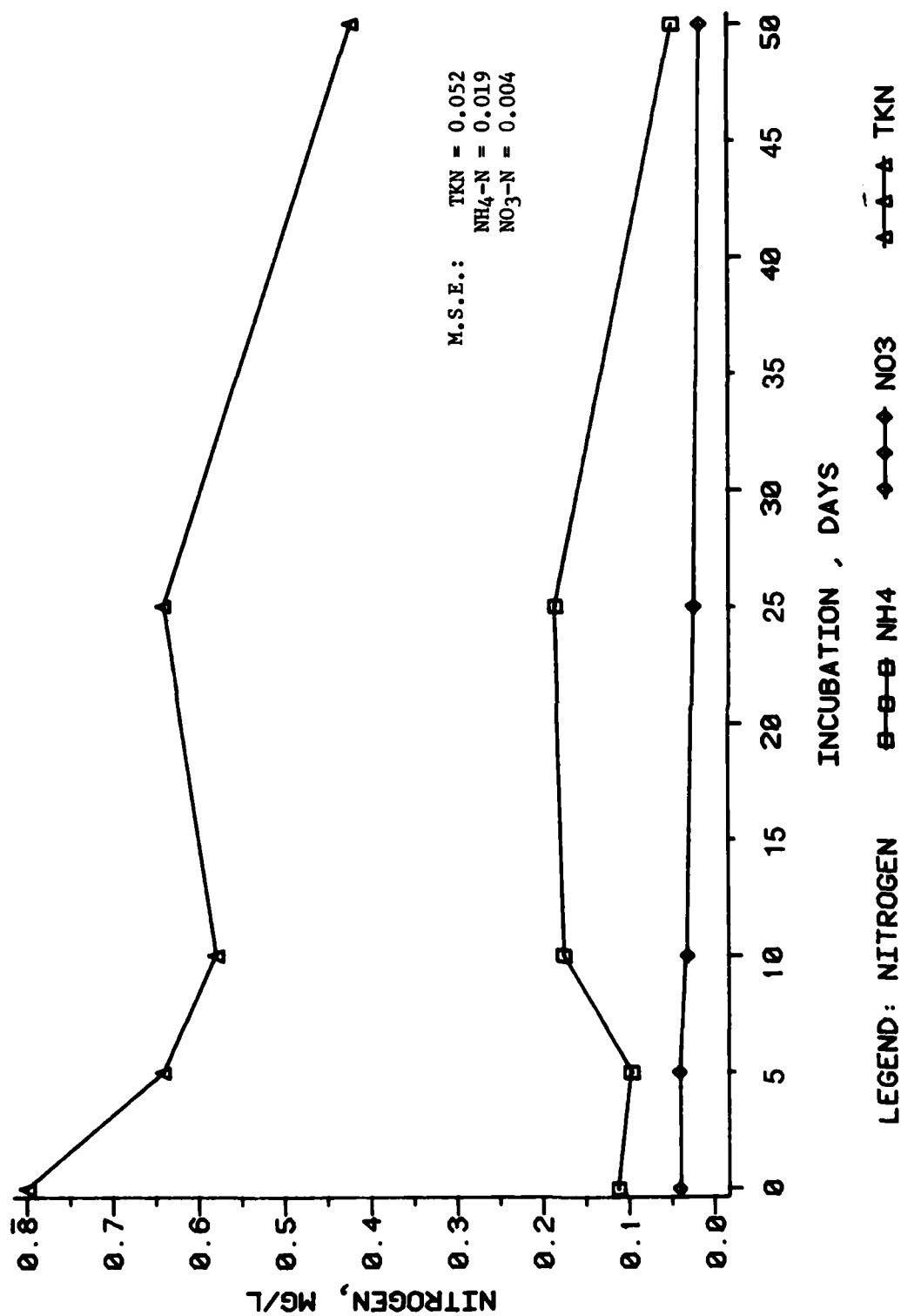
Figure 19. Changes in TKN, NH_4-N, and NO_3-N in water columns of decomposition reactors during 50-day incubation period
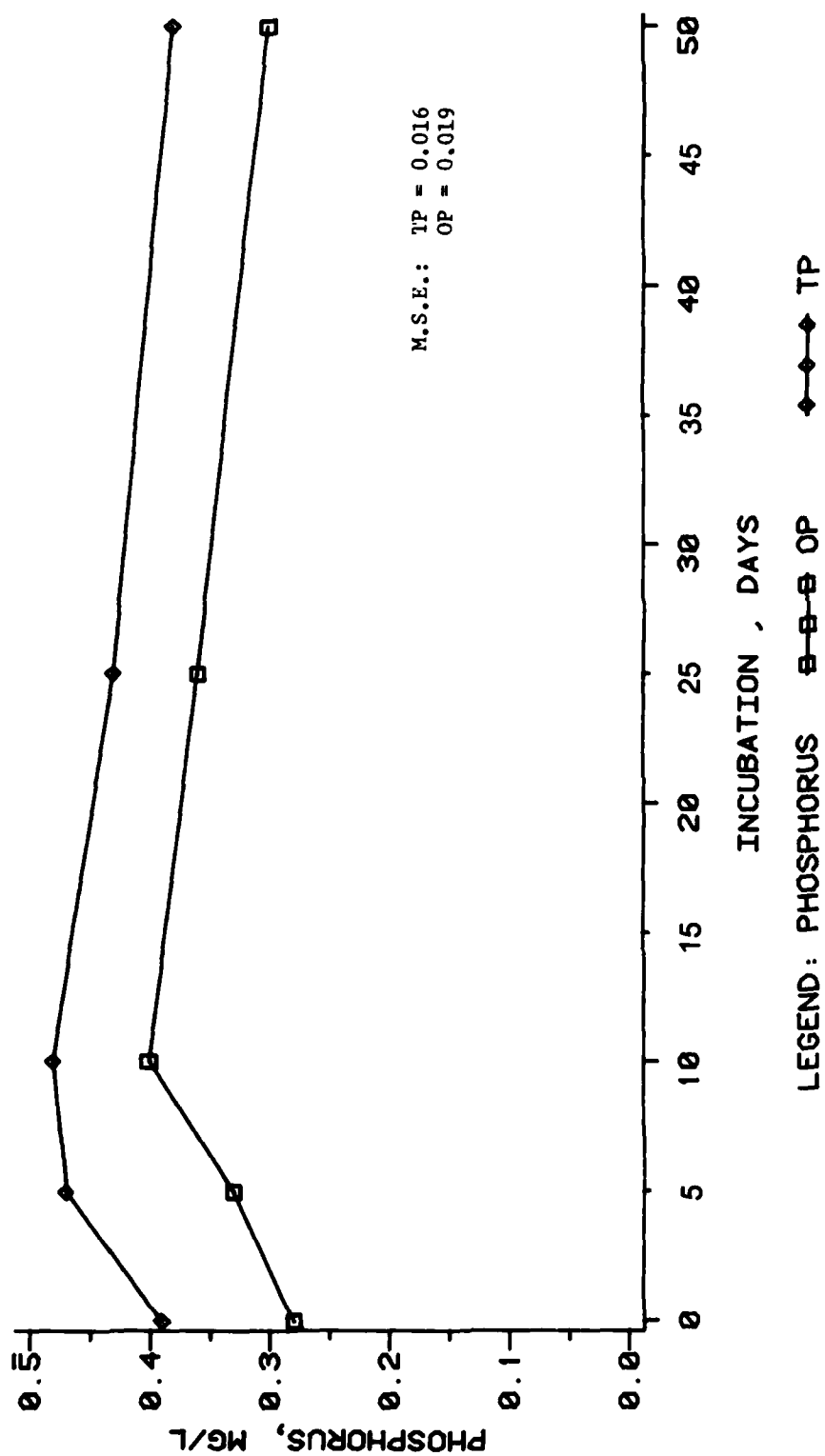
Figure 20. Changes in TP and OPO$_4$-P (OP) in water columns of decomposition reactors during 50-day incubation period
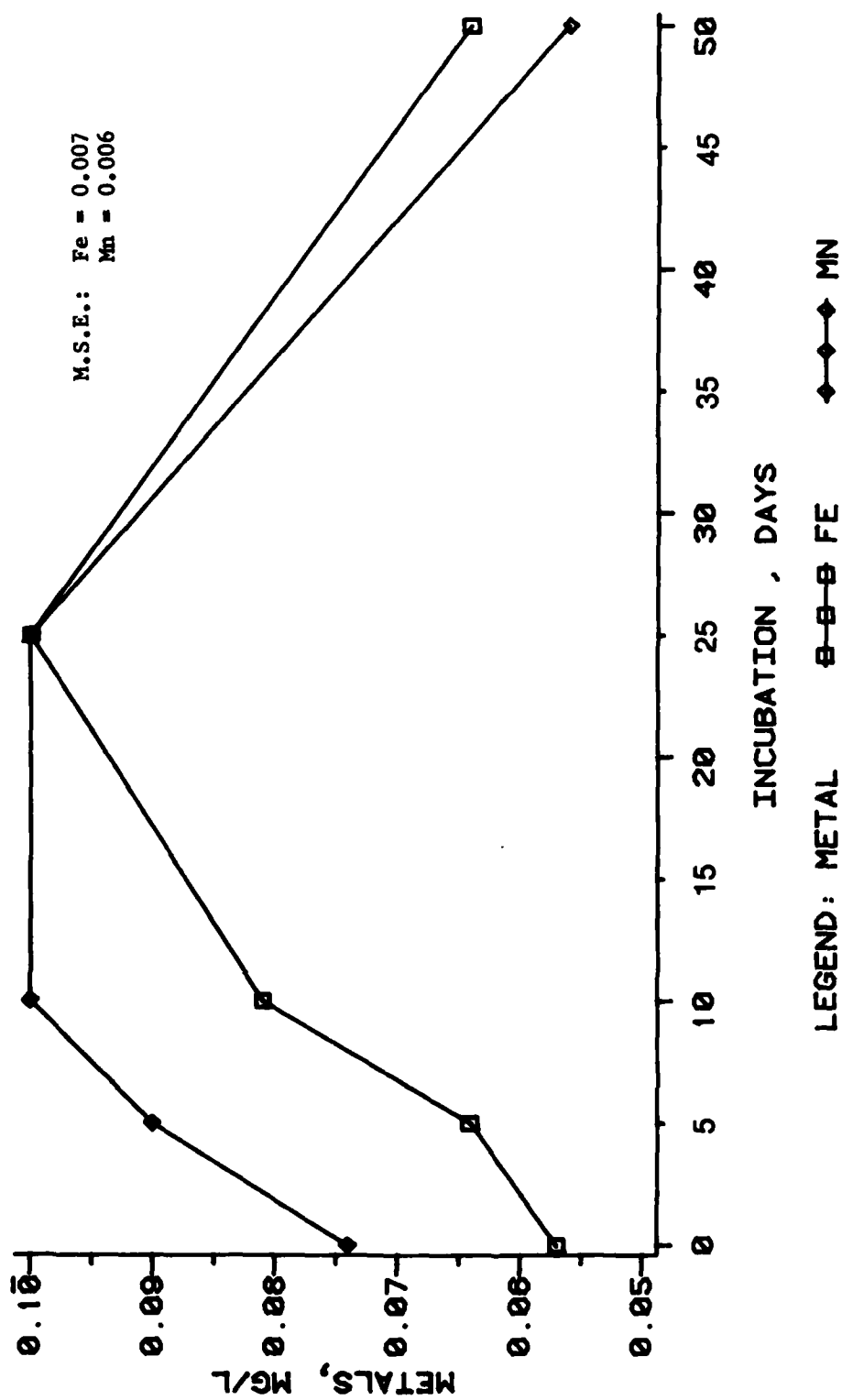
Figure 21. Changes in Fe and Mn in water columns of decomposition reactors during 50-day incubation period

PART IV: DISCUSSION

Changes Expected in Water Quality as a Result of Impoundment

58. Results of this study indicated that, following impoundment
of this portion of the Savannah River as described for U. S. Army Engi-
neer District, Savannah (1974), the changes that may be expected in the
water quality of the Savannah River should follow the trends presented
in the following discussion. This discussion is based on the assumption
that the sites sampled were representative of the area to be covered by
the lake. This discussion is also based, in large part, on the results
obtained at 20°C. While hypolimnetic temperatures near the dam are more
likely to reach the 14-16°C range, upstream hypolimnetic temperatures
may well reach 20°C. In addition, rates of decomposition and of nutri-
ent and metal releases tend to increase exponentially with respect to
increasing temperature. Based on these two points, this discussion,
while a worst-case estimate, will present a better picture of what may
happen in the reservoir than would discussions based on the 5° or
12.5°C studies.

Depletion of DO

59. High BOD values of the soil and vegetation samples taken
from the study sites will likely cause significant depletion of the
levels of DO in the overlying waters, particularly if the impoundment
develops strong thermal stratification. Oxygen depletion rates observed
for the first 100 days of inundation of the soil samples in the present
study fell close to the ranges observed in certain other reservoirs
(Gunnison et al. 1979; U. S. Army Engineer District, Portland 1978;
Sylvester and Seabloom 1965); see Table 4 for a summary of these data.
However, such comparisons between reservoirs suffer from the overall
site-specific properties of individual reservoirs. Nonetheless, with
oxygen consumption rates of 183 mg O_2/m^2/day exerted by the newly
flooded soils, bottom waters will tend to become anoxic quickly if the
lake becomes stratified with bottom temperatures in the 20°C region.
Actual in-lake oxygen depletion times depend upon (a) the depth of the

water column between the bottom of the reservoir and the hypolimnetic-metalimnetic interface and (b) the nature and fate of organic loadings entering the hypolimnion from the watershed above the reservoir and in from the edges and epilimnion of the reservoir, plus two additional factors considered in the following paragraph.

60. Water in the 5° and 12.5°C studies did not become anoxic. However, soil oxygen demand did result in significant and prolonged depression of DO levels below incoming flows. This has added significance when placed into the context of a system wherein waters entering an impoundment area may be in the 5° to 12.5°C range, but may not necessarily be saturated with DO, as was the case in this study. In the present case, if, as one source indicates, waters released from Hartwell Dam have low levels of DO (2 to 4 mg/ℓ),[*] then oxygen demand by the newly flooded soils may be intense enough to remove all DO, even at 5°C. However, it is also important to note that instream reaeration of the Savannah River can occur between Hartwell Dam and wherever the river plunges below the Richard B. Russell pool. To what extent this will influence hypolimnetic DO levels cannot be evaluated at this time. It is presently beyond the state of the art to simulate cumulative effects in the laboratory. The study did not consider the changes in water quality of a parcel of water over Site 1 that might occur had the same parcel of water previously been exposed to Sites 2 and 3, as would be the case in the actual impoundment. Finally, none of the procedures considered overall lake hydrodynamics.

61. Once the study sites have been flooded for 3 to 4 years, the oxygen demand will diminish somewhat due to the losses of some of the readily available organic matter through decomposition, leaching, and/or suspension and washout of particulates. The present study makes no pretense of accounting for whatever alteration in oxygen demand may occur because of inflow and deposition of inorganic soil components over the existing soil, nor does this study examine the potential sustaining effect or increase in oxygen demand that may occur should additional soils

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* Unpublished report, U. S. Fish and Wildlife Service, 1979.

of the existing type be washed in and deposited, thus replenishing the existing materials. Should the bottom waters remain aerobic during the first year of impoundment, a larger decrease in the oxygen demand would tend to occur as a consequence of a more efficient and complete utilization of organic matter under aerobic conditions relative to anaerobic circumstances (Alexander 1977, Brock 1967, Thimann 1963).

62. Inundation of vegetation is expected to result in a BOD that is initially fourfold to twentyfold greater than that of the soil at 20°C (Table 5). Vegetation is very labile while soil serves as a steady slow-release type of material, and the BOD of the vegetation should be comparable to the BOD of the soil after 50 days of incubation at 20°C. The case for COD is similar to that for BOD (Table 5), but the COD will be many orders of magnitude larger because of its more general characteristics. While BOD is a measure of oxygen demand exerted by materials that are readily available to microorganisms, COD includes BOD plus materials less readily available to microorganisms plus materials that are oxidizable only chemically.

Release of C, N, and P

63. Results of the present study indicate that release of organic forms of C, N, and P from the soils into the water column occurs extensively, even under fully aerated conditions. Release of organic materials from these soils is not suprising in view of the large amounts of organic matter originally present. The TOC content of Sites 1, 2, and 3 averaged 4.7 percent; this translates into a total organic matter content of 8.09 percent using the transformation factor (1.72) of Broadbent (1953). This concentration is an average of the entire soil sample, exclusive of the topmost layer of litter, but including all underground macroorganic matter.

64. The values for the total dissolved organic and inorganic forms of C, N, and P presented herein are not necessarily the actual concentrations that will be achieved in the natural ecosystem; such final values will, of necessity, be determined by the movement of nutrients from sediment to the water column and by mixing within the water column itself. Water columns of reservoirs are, under stratified

45

conditions, not as well mixed as the reaction columns used for this study. Microstratification will tend to prevent the net flux of materials released from the flooded soils evenly throughout the water column, and the concentration of nutrients will increase significantly toward the bottom of the water column. Alternatively, a river that plunges and flows along the bottom of the reservoir will immediately pick up nutrients as they are released from the flooded soil. The exact impacts of these processes on the chemistry of Richard B. Russell Reservoir and releases made from this reservoir cannot be predicted at this time.

65. The maximum levels of organic C released from the soil in this study (approximately 15 mg/ℓ) are sufficient to tie up nearly 42 mg/ℓ of DO, assuming all carbon to be metabolizable to CO_2. The values for vegetation are of a similar magnitude, although, on a milligrams per square metre per year basis, this is sufficient to combine with 26.7 to 111 g of DO. Even at more dilute concentrations, a capacity to exert a BOD will be present.

66. The N and P values present in organic materials after the release of the latter from the soil do not represent as much of a direct contribution to the pool of plant-growth stimulating nutrients as do their inorganic counterparts. If the proposed impoundment does go anoxic during the first year of filling, the subsequent buildup of inorganic nutrients will, up to a period of 50 to 60 days, show gradual increases in inorganic C, OPO_4-P, and NH_4-N. These substances, if released downstream or if released to the surface waters during the next period of mixing, represent a source of plant-growth nutrients. Moreover, the concentrations of ammonium observed in this study are high enough to cause difficulties with BODs exerted in downstream reservoir areas as a consequence of the biological oxidation of ammonium to nitrate and nitrite.

Release of sulfide

67. The SO_4 content of the water over the flooded soils is high, ranging from 14 to 40 mg/ℓ at all three temperatures studied (Figure 11). If the proposed impoundment follows the trends observed in the 20°C

studies, it will become anoxic; if it remains anoxic for a number of weeks, hydrogen sulfide will be released into the water column. While the resultant levels of sulfide in the water can be limited to a certain extent by the formation and precipitation of insoluble ferrous sulfide, the possibility cannot be excluded that some of the sulfide will escape, releasing its rotten egg odor from the lake. More likely, however, is the potential release of sulfide (primarily in the suspended particulate ferrous sulfide form) with any bottom withdrawals made from the reservoir and subsequent odor and oxygen demand problems downstream from the impoundment. Because of its lower sulfur content, vegetation would be less important than soil in this regard.

Release of Fe and Mn

68. The levels of Fe, and to a lesser extent Mn, released from soils into the water column are fairly high by virtue of the solubility of their reduced forms and approach those achieved under anaerobic conditions in optimum situations (Brannon et al. 1978). Reaeration of anoxic waters generated during this study produced a reddish coloration due to formation of ferric oxyhydroxides, which are produced when anaerobic waters containing ferrous iron are exposed to oxygen (Figure 22). Bottom withdrawal from an anoxic hypolimnion would, therefore, produce a reddish coloration in downstream waters. Insoluble ferrous sulfides may also be released during bottom withdrawals. Once released, materials such as ferrous iron and ferrous sulfides oxidize rapidly, resulting is problems with odors (sulfide) and oxygen demand (BOD and immediate oxygen demand (IOD)). Reduced Mn is more slowly oxidized and would pose a longer term oxygen demand problem.

Color

69. The findings of this study indicate that the reddish coloration acquired by waters that contact soils having high levels of Fe in the area of this impoundment will be apparent for the first 1 or 2 years both in the waters in the impoundment and in its releases. This will be true whether or not the waters become anoxic.

pH and conductivity

70. The pH will remain near neutrality under anaerobic conditions

47

Figure 22. Soil-water reaction chambers after 120 days
of incubation. Chamber on left was sealed for the en-
tire period while chamber on right was reaerated after
100 days of incubation

but will tend to become slightly acidic aerobically; however, the huge
buffering capacity of the soil system will prevent the pH from dropping
to unacceptable levels. The increase in conductivity observed in this
study indicated a gradual increase in dissolved substances under anaer-
obic conditions; this was confirmed by the observed increase in inor-
ganic forms of C, N, and P.

Influence of Site Preparation on Water Quality

Influence of reservoir clearing

71. The results obtained in this study indicate that the BOD of
vegetation from the study sites is high. The samples of vegetation

were predried and ground in order to obtain a uniformity of substrate
to enable site-to-site and vegetation-to-soil comparisons; preparation
of vegetation samples in this study would tend to increase the BOD val-
ues to some extent because of the effect of increased surface area upon
microbial availability and colonization (Alexander 1977, Sylvester and
Seabloom 1965). However, the data do fall within the range of values
obtained by other investigators (Sylvester and Seabloom 1965, Feng and
Hyde 1967). The values for the vegetation were initially 4 to 20 times
that exerted by the soil samples tested.

72. The practice of leaving vegetation in the hypolimnetic
region where residues of dead trees and shrubs can have negative impacts
on water quality is undesirable for the present impoundment. The BOD of
this shrubby and herbaceous material is exerted by substances that are
relatively easily decomposed when compared with material from a mature
climax forest. Removal of bottomland herbaceous vegetation would con-
siderably reduce the BOD of the sites studied (on a per square metre
basis). This procedure will reduce the project's impacts on water
quality, particularly in the first 1 to 3 years after filling. A plan,
originally conceived within SAS, to burn herbaceous vegetation has
merit, particularly if accomplished just prior to the winter rains; the
latter will move nutrients released by the burn out of the project area.

Influence of soil removal

73. The soils of the study sites together with the layers of
litter have a large BOD, which is reflected in the rapid oxygen deple-
tion rates observed in the soil-water reaction units. Although cost
prohibitive, removal of the upper soil horizon would decrease the oxy-
gen demand for the first years after flooding. Moreover, preliminary
results obtained in the studies of the lower horizons suggest that
these layers will release a much lower level of plant-growth-supporting
nutrients to the overlying water. Note that no attempt is made here to
anticipate the amount or nature of A-horizon materials that will enter
the reservoir from upstream areas and settle in the reservoir. Obvi-
ously, materials of a highly organic nature will tend to aggravate the
DO depletion; those of a more mineral nature will tend to seal off the

49

bottom of the reservoir after deposition and thus lower any oxygen
demand.

Influence of filling practices

74.   Because both the color and oxygen demand problems improve
upon reflooding and reexposure of the soil to fresh waters, the prac-
tice of filling and flushing the impoundment two to three times prior
to final filling can have a positive effect on reservoir water quality.
However, since much of the aging process depends as much on the break-
down of moderately degradable components (cellulose, hemicellulose) as
on the movement of readily soluble components out of the reservoir,
those filling practices that tend to accelerate degradation of organic
matter while avoiding severe BOD problems are advisable. This suggests
a sequence involving two or three flushings to remove easily soluble or
leachable components, followed by slow incremental filling to keep the
reservoir shallow for as long as possible to promote oxygen exchange
with the atmosphere and consequent efficient decomposition of organic
matter.

75.   A series of fillings and flushings will be difficult to apply
to the Richard B. Russell project with its particular relationship of
being downstream from one reservoir and immediately upstream of another.
The project also lacks selective withdrawal facilities and, therefore,
also lacks the ability to discharge only from the epilimnion until the
end of the transition phase. Some degree of benefit can be achieved by
allowing as much water as possible to pass through the sluice gates
during the initial filling and for the first 3 to 4 years after filling.
This will further decrease the retention time of water in the hypo-
limnion and serve to move materials out of the project as soon as they
are released rather than permitting them to accumulate.

Influence of oxygen injection on releases

76.   Injection of oxygen into releases from the anoxic hypo-
limnion of the Richard B. Russell Lake will have some positive effects.
Increased levels of DO will rapidly oxidize reduced Fe and sulfide, the
two principal components of a high IOD. The resulting ferric oxyhydrox-
ide floc will tend to be a good agent for adsorption of OPO_4-P, thus

50

removing a plant-growth nutrient from the dissolved readily available form in water. Addition of DO to the system on a continuous basis will help to promote aerobic decomposition of compounds released from degrading soil organic matter and vegetation.

77. Formation of a red iron oxyhydroxide floc can have some undesirable consequences. The potential formation of a red iron oxyhydroxide precipitate in the tailwaters of Richard B. Russell as they enter Clarks Hill Reservoir may have a negative aesthetic impact. Moreover, the appearance of a material in its oxidized state may create the impression that all problems with low/no DO have been taken care of, when they have not. For example, injection of oxygen can raise the DO in the tailwaters. However, this does not mean that all biological and chemical oxygen demands have been satisfied. Oxidation of ammonium, reduced Mn, and organic acids and alcohols may require miles of an aerobic river reach to be accomplished. If, instead, these materials are part of an aerated but plunging inflow entering another reservoir, the net result may be a hypolimnion that develops anoxia more rapidly with the new inflow than it did previously.

PART V: CONCLUSIONS AND RECOMMENDATIONS

78. Under aerobic conditions, the impact of the organic material released from soils and vegetation on water quality is larger in terms of the BOD exerted by the material itself than of the concentrations of plant nutrients that may be accumulated. The magnitude of the oxygen demand depends on the residence time of the water in the reservoir. By permitting as much hypolimnetic water as possible to pass through the sluice gates, the project operation will decrease hypolimnetic residence time and help lower the oxygen demand.

79. Anoxic conditions can develop if hypolimnetic temperatures approach 20°C or if inflows contain low DO. Once anaerobic conditions have developed, both organic and inorganic forms of C, N, and P predominate for the first few weeks of impoundment, but NH_4-N and OPO_4-P make up increasingly larger portions of total N and P as anaerobic incubation continues. Accumulation of C, NH_4-N, and OPO_4-P will continue to increase throughout the entire period of anaerobic incubation as will the reduced forms of Fe and Mn. Bottom withdrawals from the reservoir under these conditions would release significant concentrations of ferrous iron and manganous manganese and inorganic forms of C, N, and P. These constituents could also be combined with the surface waters during periods of wind-induced mixing. To make actual projections of the values for the reservoir, the data obtained in this study should be used with a mathematical water quality model that simulates reservoir biological and chemical processes along with the physical processes.

80. After 40 to 50 days of incubation (average 10 days of anoxic conditions), sulfide accumulation was observed in these studies. The detection of sulfide in the water column corresponded to the observation of a black precipitate of ferrous sulfide and the unpleasant odor characteristic of hydrogen sulfide apparent in water samples taken at this time. Bottom withdrawals under these conditions without oxygen injection would have sulfide problems.

81. Studies of the BOD of vegetation from the sites examined indicated that the vegetation will have an initial BOD of from 4 to

20 times that of the soil. The shrubby and herbaceous nature of much of the vegetation at the study sites indicated that much of the growth was easily decomposed. Removal of this bottomland vegetation should improve the oxygen demand, although quantitative data are not available at this time. The initial BOD of samples of soil plus vegetation combined was in the range of from 5,740 to 20,500 mg O_2/m^2. This demand decreased by approximately 3,000 mg/m^2 after 50 days of flooding, primarily due to decomposition of labile vegetation.

82. In addition to the recommendations concerning use of sluice gates and application of a mathematical water quality model, we suggest the following:

a. SAS should follow its suggested plan to burn residual herbaceous vegetation in the impoundment area. It is important that (1) this be done immediately prior to the winter rainy season to promote flushing of burn-released nutrients out of the system and (2) should any delay in filling occur that permitted regrowth of herbaceous vegetation, the regrowth should be burned also.

b. SAS should not permit tree parts to be dropped into project waters during tree topping operations. Instead, these materials should be removed from project waters within a short period of time.

c. SAS should develop a firm water quality monitoring program for the Richard B. Russell project. Monitoring would provide guidance for project operation during the initial filling and during the transition phase. For this reason, rapid turnaround of sample data from an analytical laboratory is important. Dissolved oxygen data are particularly critical, and we recommend in situ monitors for the hypolimnion upstream of the continuous diffusers, downstream from the continuous diffusers, and near the dam, but not over the intermittent oxygen diffuser system. Project releases should also be monitored.

d. SAS should be prepared to operate the oxygen injection system from the start of filling and, based on the guidance provided by the water quality monitoring program, perhaps continuously throughout the transition phase.

53

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Table 1

Concentrations of Water-Extractable Chemical Constituents in Soils from the Impoundment Area

	Concentration, µg/g of Soil*		
Constituent	Site 1	Site 2	Site 3
Calcium	7.0 ± 0.45	46.9 ± 6.0	4.8 ± 0.68
Magnesium	3.5 ± 0.41	18.1 ± 1.6	2.1 ± 0.34
Potassium	9.3 ± 0.40	17.5 ± 0.69	0.5 ± 0.52
Sulfate	55.0 ± 17.0	73.3 ± 6.5	8 ± 0

* Data are expressed as the mean ±95 percent confidence interval.

Table 2

Concentrations of Extractable Chemical Constituents in Soils from the Impoundment Area

	Concentration, µg/g of Soil*		
Constituent	Site 1	Site 2	Site 3
Ammonium acetate extractable			
Iron	8.25 ± 1.78	7.50 ± 1.01	3.71 ± 0.48
Manganese	71.0 ± 7.40	292 ± 9.45	43.0 ± 6.00
Orthophosphate phosphorus	0.390 ± 0.010	4.10 ± 0.14	0.375 ± 0.025
Potassium chloride extractable			
Ammonium nitrogen	10.0 ± 0.485	10.5 ± 0.250	2.01 ± 0.500
Hydroxylamine extractable			
Iron	172 ± 2.6	467 ± 9.00	177 ± 31.8
Manganese	327 ± 1.25	955 ± 6.90	420 ± 48.2

* Data are expressed as the mean ±95 percent confidence interval.

Table 3

General Physical and Chemical Properties of Soils

from the Impoundment Area

Constituent	Concentration*		
	Site 1	Site 2	Site 3
TKN, μg/g	202 ± 18.3	357 ± 5.29	78.1 ± 3.94
Total iron, μg/g	17,575 ± 505	36,675 ± 2,089	13,500 ± 552
Total manganese, μg/g	442 ± 8.2	1,465 ± 44.0	512 ± 28.8
Total phosphorus, μg/g	115 ± 5.1	1,595 ± 32.8	114 ± 9.4
Cation exchange capacity, meq/100 g soil	0.15	0.15	0.15
Total organic carbon, percent	5.22 ± 0.175	7.22 ± 0.147	1.63 ± 0.243
Total inorganic carbon, percent	0.02 ± 0.008	0.04 ± 0.008	0.02 ± 0.014
Particle-size analysis			
Sand, percent	50.0	51.2	88.8
Silt, percent	30.0	29.4	8.1
Clay, percent	20.0	19.4	3.1

* Data are expressed as the mean ±95 percent confidence interval.

Table 4

Comparison of Dissolved Oxygen Consumption Data for Soils

and Sediments from Various Freshwater Ecosystems

Source	O_2 Consumption $g/m^2/day$	Reference
Lost Creek Lake, Washington	0.83-1.69	U. S. Army Engineer District, Portland (1978)
Green Bay, Wisconsin	0.16-0.48	Bowman and Delfino (1980)
Scandanavian lakes	0.32-1.5	Edberg and Hofsten (1973)
Scandanavian streams	0.26-1.2	Edberg and Hofsten (1973)
Sludge deposit downstream from a sewage treatment plant	0.48	Bowman and Delfino (1980)
Wild Rice River, Minnesota	0.410	Gunnison et al. (1979)
Pasture soil, Mississippi	0.330	Gunnison et al. (unpublished data)
New Hope River, North Carolina	0.098	Gunnison et al. (unpublished data)
Savannah River, Georgia and South Carolina	0.183	This study

Table 5

Comparison of Water Quality Initially and After 50 Days of Incubation with Soil and Vegetation at 20°C

| Constituent* | Incubation Period, days | | | |
| | Soil** | | Vegetation† | |
	0	50	0	50
Biochemical oxygen demand	1,086	1,080	4,650-19,375	554-2,310
Chemical oxygen demand	32,000	25,185	28,380-118,250	12,420-51,750
Carbon				
Total organic carbon	5,136	2,963	9,600-40,000	5,280-22,000
Total inorganic carbon	0	35,592	0	1,680-7,000
Nitrogen				
Total Kjeldahl nitrogen	410	2,356	400-2,000	253-1,060
Ammonium nitrogen	7.90	1,307	67.2-280	26.4-110
Nitrate + nitrite nitrogen	264	16.8	26.4-110	12.0-50.0
Phosphorus				
Total phosphorus	0	276	235-980	228-950
Orthophosphate phosphorus	0	160	172-718	178-742
Iron	47.4	10,350	34.2-142	38.4-160
Managanese	41.5	7,600	44.4-185	33.0-138

* All data are expressed as milligrams per square metre.
** Soil contribution computed by multiplying amount present per litre in reaction chamber times volume of chamber (200 ℓ) and dividing by the soil surface area (0.2025 m^2).
† Vegetation contribution computed by multiplying release (milligrams of constituent per gram of plant material) by Leith's (1975) estimate for net primary production in a warm temperate mixed forest (600-2500 g/m^2/year), assuming that all of the year's production is present at the time of flooding.

APPENDIX A: SOIL-WATER REACTION CHAMBERS*

1. The reaction chamber is constructed of sections of 12.7-mm-thick plexiglass bonded together with methylene chloride cement to form a rectangular tank and removable lid having the dimensions shown in Figure A1. To provide for several different experimental configurations, the reaction chamber is designed to permit placement of sampling ports in any or all of the holes in the sides of the unit (Figures A1 and A2). Unused sampling ports are plugged from inside the chamber outwards with No. 5 rubber stoppers, and complete sealing is effected by ringing both inner and outer edges of each stopper with weatherstrip adhesive. Prior to use, the chamber is washed with a low phosphorus detergent and rinsed thoroughly with distilled water.

2. For soil-water reaction studies requiring a continuous flow of water through the system, the chamber is set up in the configuration shown in Figure A3. The inflow pump shown has a variable flow rate from 8.0 to 0.4 mℓ/min, giving an effective residence time for water in the reaction column of 17.4 to 347 days, respectively. To ensure
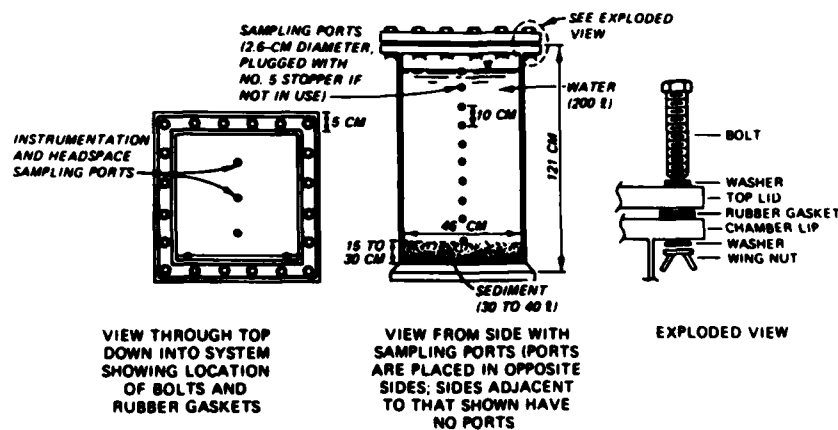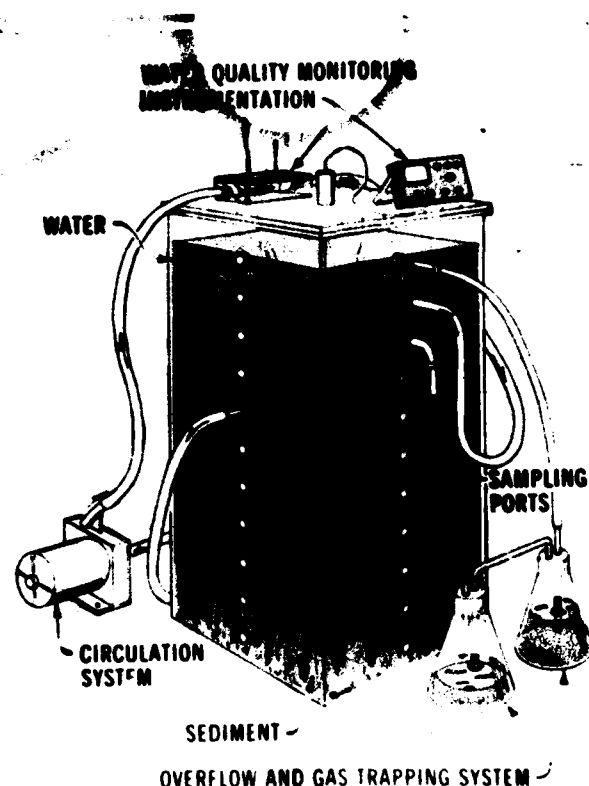

VIEW THROUGH TOP DOWN INTO SYSTEM SHOWING LOCATION OF BOLTS AND RUBBER GASKETS

VIEW FROM SIDE WITH SAMPLING PORTS (PORTS ARE PLACED IN OPPOSITE SIDES; SIDES ADJACENT TO THAT SHOWN HAVE NO PORTS

EXPLODED VIEW

Figure A1. Structural diagram of the sediment-water reaction chamber

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* Modified from Gunnison et al. (1980). See References at end of main text.

WATER QUALITY MONITORING INSTRUMENTATION

WATER

SAMPLING PORTS

CIRCULATION SYSTEM

SEDIMENT

OVERFLOW AND GAS TRAPPING SYSTEM

SEDIMENT-WATER REACTOR FOR STUDYING ANAEROBIC CONDITIONS IN RESERVOIRS

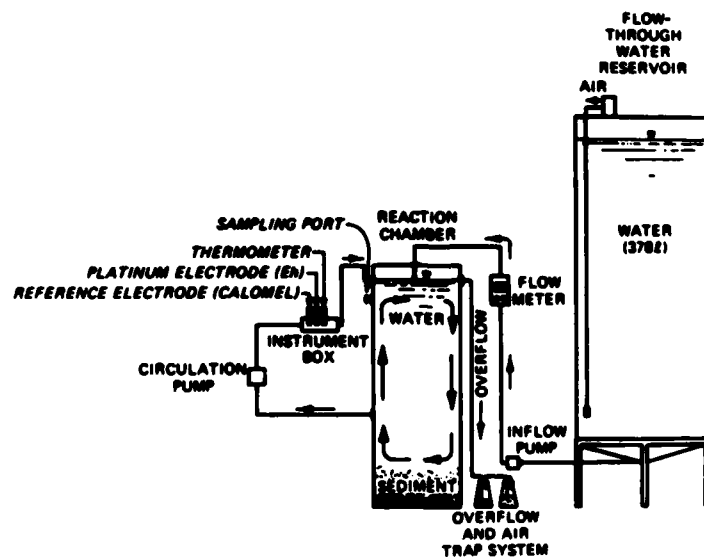Figure A2. Three-dimensional diagram of reaction chamber (Gunnison et al. 1979)

Figure A3. Schematic diagram of the reaction chamber and continuous flow system

complete assimilation of inflows with the water column, the water column is mixed using a circulation pump having a capacity sufficient to turn over the entire volume of water once every 2 min. Reaction chambers are encased with sheets of black polyethylene to prevent growth of oxygen-producing algae during prolonged incubation periods. An overflow air trapping system is used to capture outflows while simultaneously preventing entry of air into the chamber (Figures A2 and A3). This system also permits the escape of excess gas pressure produced in the chamber.

3. In normal operation, a sample of soil profile representative of the preimpoundment site is trimmed to fit inside the reaction chamber (0.45 × 0.45 × 0.15 m high), and this is then gently lowered into the chamber. The remainder of the column is filled to the level of the uppermost stopper (volume of water approximately 200 ℓ) with water chemically formulated to approximate the average yearly composition of the stream to be impounded. The reaction column is permitted to equilibrate for 4 weeks with mixing and aeration, but no inflows. At this time, aeration of the reaction chamber is terminated, and the chamber is sealed from atmospheric contact by tightening the nuts and bolts (Figure A1), thus compressing the rubber gasket. A final seal is obtained by applying a coat of weatherstrip adhesive around the outside edge of the lid-to-chamber interface. Inflows are then started.

APPENDIX B: ANALYTICAL METHODOLOGY AND DETECTION LIMITS
OF WATER QUALITY PARAMETERS*

Parameter	Method	Detection Limit	Reference**
Sulfate	375.4	5 mg/ℓ	U. S. Environmental Protection Agency (1979)
Orthophosphate phosphorus	365.1	0.01 mg/ℓ	
Nitrate nitrogen	353.2	0.01 mg/ℓ	
Chemical oxygen demand	410.2	5 mg/ℓ	
Ammonium nitrogen	350.1	0.01 mg/ℓ	
Total Kjeldahl nitrogen	351.2	0.10 mg/ℓ	
Total phosphorus	365.4	0.10 mg/ℓ	
Iron	236.1	0.05 mg/ℓ	
Manganese	243.1	0.05 mg/ℓ	
Potassium	258.1	0.05 mg/ℓ	
Calcium	215.1	0.05 mg/ℓ	
Chloride	325.3	5 mg/ℓ	
Magnesium	242.1	0.05 mg/ℓ	
Sulfide†	427C	0.1 mg/ℓ	American Public Health Association (1980)
Disolved oxygen	421B	20 µg/ℓ	
Total inorganic carbon	505	0.1 mg/ℓ††	
Total organic carbon	505	1 mg/ℓ	
Biochemical oxygen demand	507	5 mg/ℓ	

* Methods of preservation and storage are given in the indicated reference.
** See References at end of main text.
† Detection limit for sulfide can be lowered severalfold by use of zinc acetate to concentrate the sulfide (American Public Health Association 1980, method 427B).
†† Beckman Model 865 Infrared Analyzers, Beckman Instruments, Inc., Fullerton, Calif. (1975).

APPENDIX C: QUALITY CONTROL EFFORTS

1. Analytical instruments were calibrated daily using certified standards traceable to National Bureau of Standards (NBS) reference materials. Analytical balances were set to zero before each reading and checked against NBS Class S reference weights. All instruments were on maintenance contracts to ensure continuous operation at the manufacturer's specifications. Sample blanks were processed and analyzed for all analytical procedures and NBS reference materials were analyzed as samples to check for possible procedural errors.

2. The Analytical Laboratory Group which conducted this study participates in the U. S. Environmental Protection Agency (USEPA) round-robin quality control efforts. Statistical quality control efforts were incorporated daily as outlined in "Handbook for Analytical Quality Control in Water and Wastewater Laboratories" (USEPA 1972).* Every eighth sample was duplicated and spiked to ensure proper precision and accuracy. Quality control efforts also involved blind sample splits for precision evaluation and blind analysis of standard reference samples for accuracy evaluation

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* See References at end of main text.

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